RESISTANCE TO CHANGE, DELAYED REINFORCEMENT, AND MASS RATIO INVARIANCE.

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CONTENTS.

LIST OF FIGURES.

Page

LIST OF TABLES.

Page

ABSTRACT.

Two experiments evaluated relative resistance to change in a two-component single-key multiple schedule where components differed in reinforcement delay. In Experiment 1, responding was disrupted using prefeeding, response-independent food presentations during the intercomponent interval (dark-key food), extinction, and a concurrent distracting stimulus. Consistent with Behavioural Momentum Theory, response-rate reduction was proportionally greater in the component with an 8 second reinforcer delay than the component with a 1 second reinforcer delay. However, when calculated using the average proportion of baseline (APOB) method, mass ratios (a measure of relative resistance to change) varied systematically as a function of disruptor magnitude. This is not consistent with Behavioural Momentum Theory. Experiment 2 obtained similar results in a procedure in which the intercomponent interval was signalled by illuminating the houselight. The average proportion of baseline method of calculating mass ratios has a number of advantages over the ratio of slopes method used in recent resistance to change studies, and while the mass ratio variance that is obtained using the APOB method is inconsistent with Behavioural Momentum Theory, it is predicted by the Quantitative Law of Effect.

1.1 RESISTANCE TO CHANGE.

Resistance to change is a feature of behaviour with important implications for both experimental and applied behaviour analysis. In experimental analysis, differential resistance to change has attracted considerable attention, and a classic example of this is the Partial Reinforcement Effect.

The Partial Reinforcement Effect is clearly demonstrated in the results of a study conducted by Boren (1961) which examined resistance to extinction as a function of fixed ratio schedules. Boren showed that the total number of responses emitted during the course of extinction was inversely related to reinforcement rate, and that responses receiving intermittent reinforcement were therefore more resistant to extinction than those maintained by continuous reinforcement (CRF). This was consistent with earlier findings (e.g. Wilson, 1954), and the Partial Reinforcement Effect is now established as a phenomenon with particular importance in applied behaviour analysis.

On a theoretical level the Partial Reinforcement Effect poses something of an enigma. The issue of why responses receiving intermittent reinforcement should develop more resistance to extinction than those maintained on CRF is an interesting one and the problem has been referred to as "Humphreys' Paradox" after the psychologist who identified the Partial Reinforcement Effect in 1939. The enigma arises because the Partial Reinforcement Effect runs counter to intuitions regarding the effect frequent reinforcement should have on behaviour. A more frequently reinforced response should be stronger than a less frequently reinforced alternative, and therefore, in contrast to the Partial Reinforcement Effect, be more resistant to extinction.

The identification of response strength with the ability to resist change has an established, even illustrious history. In an early expression of this view, Pavlov explicated the strength of a classically conditioned reflex in terms of its latency, amplitude, and its ability to resist change (see Nevin, 1979). Later, Hull's elaborate (1943) theory posited 'reaction potential' as a concept that was virtually synonymous with response strength (ibid, p 118). The related theoretical construction of habit strength is a change effected in the nervous system of an organism as the result of reinforcement, and this change manifests itself "in a measurable manner in its

resistance to the effect of repeated evocations unaccompanied by reinforcement" (Hull, p 106). This appeals to the idea that strong responding is reflected in the ability to resist change; well-established habits are those that display "a certain resistance to extinction" (ibid, p 109).

Behavioural Momentum Theory (Nevin, 1988, 1992a; Nevin, Mandell and Atak, 1983) is a more recent account of resistance to change that also identifies response strength with the ability to resist disruption (e.g. Nevin, 1974, 1979).

1.2 BEHAVIOURAL MOMENTUM THEORY: A REVIEW.

1.2.1. Relative resistance to change.

Behavioural Momentum Theory is an account of differential resistance to change. It is concerned with relative resistance to disruption, usually in respect of two components in a multiple schedule, and is conceptually based upon a metaphor adopted from physical dynamics. Nevin proposes that like physical objects, operant behaviour possesses the property of momentum, and this is defined as some function of behavioural velocity (equated with response rate) and behavioural mass (equated with resistance to change).

The logic of the physical metaphor suggests that resistance to change is revealed when some disruptor (construed as a force) is applied to responding. Large reductions in responding indicate low mass and vice versa. Using this logic, behavioural momentum research employs an uncomplicated procedure. Two responses are maintained in a multiple schedule arrangement, a stable level of baseline responding is established, and the same disruptive force is then applied to each component. As with the dynamics of physical objects, greater resistance to change, or mass, is revealed in the response that is disrupted least.

Various disruptors have been used in the course of resistance to change research. In Nevin's studies, these typically include extinction, response independent food provided during an intercomponent interval (dark-key food), and satiation (prefeeding). The effects of superimposed shock (e.g. Bouzas, 1978) and conditioned suppression (e.g. Lyon, 1963; Blackman, 1968) have also been considered, but have not been routinely employed in the study

of behavioural momentum. The existence of a range of behavioural disruptors has an awkward consequence however. Comparison with the physical metaphor is confounded because there is no absolute measure of mass for behaviour as there is for physical objects. The problem arises because behavioural mass cannot be measured directly, but is expressed in units of "the disruptive variable relative to behaviour" (Nevin, 1992a, p 302). The disruptive forces vary however, and there are no commensurate units of measurement allowing comparison between forces. Because resistance to change cannot be measured in absolute terms, behavioural momentum research is restricted to a consideration of relative resistance to change (Nevin et al, 1983, p 50).

Unlike absolute resistance to change, relative mass is explicable in terms of the physical metaphor applied within the context of multiple schedule performance. Measures of relative mass can be derived from Newton's second law, $\Delta v = f/m$ (where f is applied force; m is mass). For two physical bodies (1 and 2) disrupted in their motion by some force (f), relative mass, or mass ratio, can be derived by writing Newton's formula for one body as a ratio of the other, yielding;

$$\frac{\Delta v1}{\Delta v2} = \frac{f/m1}{f/m2.}$$

When the forces are equal, $m1/m2 = \Delta v2/\Delta v1$. This indicates that for operant behaviour, relative mass (also termed resistance ratio or mass ratio) can be defined as the ratio of the velocity changes in each component of a multiple schedule, when the same force is applied to these components. In practise, relative mass is readily ascertained because behavioural velocity is equated with rate of response, an easily measured property of behaviour. To avoid floor effects that may occur when baseline velocities are low, and because behavioural mass is supposed to be independent from rate of response, velocities are nominalised by using proportion of baseline responding as a measure of velocity change when disruptive force is applied. More recently (Nevin, 1992a, 1992b), log transformed data have been used for the

same purpose. Thus, in behavioural momentum research, measures of relative resistance to change are derived from changes in response rate relative to baseline performance. It is important to note that the logic of this measure requires that both multiple schedule components are disrupted by the same force, certainly in quantitative terms. In practise, this implies qualitative equality as well.

An illustrative experiment.

In an early and typical experiment (Nevin, 1974, Experiment I), a multiple schedule was used to establish baseline conditions against which relative mass was measured using response-independent food presentations during the intercomponent interval. In baseline conditions one variable-interval schedule (VI 60s) was arranged with a green stimulus. A leaner schedule (VI 180s) was arranged in the other component and signalled with a red stimulus. Components alternated, and were separated by a 30-s blackout period. Pigeons were trained in the baseline conditions until responding in both components was stable and then, in the disruption condition, response-independent food was presented during intercomponent blackout intervals when no stimulus was present (hence 'dark-key food'). When dark-key food was introduced, responding in the rich component (green) reduced less relative to baseline than in the lean one. This effect was consistent for various rates of dark-key food and the same pattern was evident when extinction was used as a disruptor in a second experiment. Thus, when different rates of reinforcement were established in two components of a multiple schedule, responding was differentially resistant to disruption by both dark-key food and extinction.

In these experiments the rates of response differed between components, and it might be argued that differential resistance to disruption was a rate-dependent effect. However, according to Behavioural Momentum Theory, resistance to change cannot be functionally dependent upon response rate because behavioural mass and velocity are supposed to combine to produce behavioural momentum.

1.2.2. The functional independence of behavioural mass and velocity.

A number of studies support the functional independence of resistance to change from response rate. For example, Fath, Fields, Malott and Grossett (1983) used DRL and DRH contingencies that provided equal reinforcement rates but sustained different rates of response. When response independent food was applied as a disrupting force, no systematic differences in resistance to change effects were observed. This suggests that resistance to change was not a function of baseline response rates.

These results are supported by data from Nevin 1974 (p 402, Figure 9) which show a clear dissociation between rate of response and resistance to change. In this experiment Nevin compared the resistance to change effects between multiple schedule components that were reinforced according to either a VI 1-min or VI 3-min contingency, and maintained in accordance with various pacing requirements. The results demonstrated that in every case the VI 1-min component was most resistant to change, irrespective of the disruptor applied and the effects of pacing requirements. Taken together, the results from Fath et al (1983) and Nevin (1974) suggest that resistance to change is independent from response rate and imply a relationship with reinforcement rate instead.

Additional evidence is provided by data from two studies where baseline response rates were serendipitously equal, despite differences in reinforcer rate. In an experiment using pigeons Nevin, Mandell and Atak (1983) obtained differential resistance to change for multiple schedule components where baseline response rates were close to 80 responses per minute for each component. The component maintained on a high rate of reinforcement resisted disruption from dark-key food more successfully than the component maintained on a low rate. Similarly, a study by Mace, Lalli, Shea, Lalli, West, Roberts and Nevin (1990, Experiment 1) used human subjects performing in a multiple schedule (VI 60-sec VI 240-sec) where components received differential reinforcement but response rates were close to equal. Nevertheless, greater resistance to change was associated with more frequent reinforcement.

Overall, the evidence presents a strong argument in support of the functional independence of response rate and resistance to change. If resistance to change is not dependent upon rate of response, upon what does it depend?

1.2.3. The determinants of resistance to change.

It has been consistently observed (Nevin, 1974; Nevin et al, 1983; Mace et al, 1990) that more frequently reinforced responses are more resistant to change than those maintained by lower rates of reinforcement. In addition to reinforcement rate, magnitude and delay of reinforcement are important dimensions of reinforcement (cf. Baum and Rachlin, 1969) that also influence resistance to change.

A third experiment reported in Nevin's 1974 study found that the magnitude of reinforcement produced resistance effects that were "strikingly parallel to those of frequency of reinforcement" (p 395). In an experiment where multiple schedule components differed only in respect of magnitude of reinforcement, Nevin demonstrated (with one exception) that responding in the component with larger reinforcers (7.5 seconds) was disrupted less by the introduction of dark-key food than responding in the leaner component (2.5 seconds). Magnitude of reinforcement is therefore, like rate of reinforcement, a determinant of resistance to change.

Nevin's 1974 findings with reinforcer magnitude have been replicated by Harper and McLean (1992, Experiment 1). This study obtained mass differentials between two VI schedules which also differed only in terms of the duration of the reinforcers (2 seconds versus 6 seconds). When varying amounts of dark-key food were applied, the component maintained by 6 second reinforcers was most resistant to disruption.

The finding that frequency and magnitude, two dimensions of reinforcement, produce the same effects in terms of resistance to change, suggests that immediacy of reinforcement should function in an identical fashion (cf. Chung and Herrnstein, 1967; Baum, 1974). Nevin (1974, Experiment IV) used two pigeons and varied the relative delays in two multiple schedule components across conditions of the experiment. While response rates were generally

unaffected by the different immediacies of reinforcement, resistance to the disruptive effects of dark-key food was consistent with Behavioural Momentum Theory in that responses maintained by reinforcers with short delays were more resistant to disruption than those maintained by reinforcers with long delays. This effect was most pronounced for more extreme ratios of delay (1 second versus 9 seconds and 0.4 seconds against 9.6 seconds), however, the effect was also present, if less convincing for a condition with delays of 2.5 and 7.5 seconds. When extinction was used to disrupt components with delays of 9.6 and 0.4 seconds respectively, similar results were obtained.

The evidence suggests that resistance to change, or behavioural mass, is determined by the values of various dimensions of reinforcement including the frequency, magnitude and immediacy of reinforcement. This provides supporting evidence for the generality of Behavioural Momentum Theory by extending the effect across the various dimensions of reinforcement. However, because these dimensions of reinforcement determine both response rate (cf. the Quantitative Law of Effect) and resistance to change, and because rate of response and resistance to change are supposed to be functionally independent, there must be some way of distinguishing the effects of reinforcement that produce behavioural velocity from those that produce behavioural mass.

Pavlovian contingencies and resistance to change.

Resistance to change might develop as a function of reinforcement for either of two reasons (Nevin, 1988, p 45). It might occur because the response receives high values of reinforcement, or alternatively, because the stimulus associated with this response is correlated with high values of reinforcement. Nevin calls this second possibility 'Pavlovian' and distinguishes it from the first, which is regarded as 'operant'. Thus, resistance to change may be determined by either operant response-reinforcer contingencies, or by Pavlovian stimulus-reinforcer contingencies.

Nevin argues that a Pavlovian process is effective in establishing resistance to change on the basis of a study (Nevin, 1984) which used a three-component three-key multiple schedule

where identical initial stages were followed by non-contingent transitions to stages with varying rates of reinforcement. One component provided access to an increased level of reinforcement, another to a continuation of the reinforcement conditions in the initial stage, and in the third component the initial stage was followed by extinction. Thus, initial links in components were identical in terms of operant-reinforcer contingencies, but differed in respect of the reinforcement predicted by their respective stimuli. When resistance to change was assessed using prefeeding and extinction, resistance was greatest in the component which predicted the most over-all reinforcement. It was stimulus-reinforcer contingencies, therefore, that determined differential resistance to change in the initial stages where the operant contingencies were identical.

This finding is reinforced by Nevin, Smith and Roberts (1987) in a paper with the interesting title 'Do contingent reinforcers strengthen operant behaviour?'. This study found no clear resistance differences between a multiple schedule component that provided response-contingent access to a second stage and one that provided non-contingent access to an equivalent second stage. This supports the notion that the important element in the determination of resistance to change is the relationship between a stimulus and the reinforcement it predicts. In contrast, rate of response appeared to be determined by operant, response-reinforcer contingencies. Response-contingent transitions to the second stage of a component maintained higher rates of response in the first stage of that component than in the other, in which transitions were not contingent upon a response. The response-reinforcer contingency therefore affected response rate but not resistance to change.

Nevin's distinction between operant and Pavlovian contingencies, and the notion that resistance to change is determined by the latter, gains further credibility from a study (Nevin, Tota, Torquato and Shull, 1990) in which concurrent, supplementary reinforcement was provided either contingently (Experiment 2) or non-contingently (Experiment 1) in one component of a multiple schedule. Thus, in Experiment 1, one component of a multiple schedule received extra food deliveries according to a variable-time schedule. In Experiment 2, one component also received extra food deliveries, but these were contingent upon a concurrent response. In both of these experiments the rate of a target response varied negatively as a

function of alternative reinforcement (operant contingencies). Conversely, resistance to change was positively related to the overall rate of reinforcement in each component (stimulus-reinforcer contingencies), whether or not reinforcement was response-contingent. This supports the view that stimulus-reinforcer contingencies, rather than operant contingencies, are instrumental in determining resistance to change.

Evidence derived from a number of studies suggests that not only are velocity and mass conceptually and functionally independent as required by Behavioural Momentum Theory, they are determined by different features of the environment. The distinction between response-reinforcer and stimulus-reinforcer contingencies distinguishes between the effects of reinforcement that determine response rate and those that determine resistance to change. The Pavlovian contingency between a stimulus and the reinforcement it predicts emerges as the fundamental determinant of behavioural mass.

1.2.4. The generality of behavioural momentum findings.

Behavioural Momentum Theory has generality across different experiments, several dimensions of reinforcement, and various disrupting forces. In addition, evidence suggests that the effects predicted by the theory generalise well across species. While much of Nevin's research has been conducted with pigeons, it is not difficult to find similar effects using other species.

Rats exhibit resistance effects consistent with Behavioural Momentum Theory. Research conducted by Church and Raymond (1967) found a between-groups differential resistance to superimposed shock. A group trained on a VI 5-min reinforcement schedule was substantially less resistant, relative to baseline, to the superimposition of contingent shock than another group trained on VI 12-sec. A similar study (Jenkins, 1978) also used independent groups of rats but utilised reduced levels of food deprivation as a disruptive force. Response rates reduced relatively less for the continuously reinforced group than for groups trained on leaner random-ratio schedules. While these between-group effects are consistent with the expectations of Behavioural Momentum Theory, they employ an unfamiliar between-groups style of analysis.

Nevertheless, the very consistency of these results, in comparison with the more usual within-subjects design of resistance to change studies, argues in favour of their validity. For example, Church and Raymond's (1967) between-groups results with rats are directly and favourably comparable with Bouzas' (1978) within-subjects replication using pigeons. Similarly, a more familiar within-subjects procedure (Blackman, 1968) used rats in a multiple schedule which included pacing requirements to establish similar response rates. A conditioned suppression procedure was then introduced to disrupt responding, and consistent with Behavioural Momentum Theory, greater suppression was associated with the components maintained by lower rates of reinforcement.

There is ample evidence supporting the value of Behavioural Momentum Theory in relation to pigeons and rats, but little work has used human subjects. The study by Mace et al (1990), referred to previously, demonstrated a differential resistance effect with intellectually disabled humans when rates of reinforcement differed between two multiple schedule components. A second experiment with the same subjects used two VI 60-sec schedules, one of which was supplemented with DRO reinforcement. Consistent with the notion that stimulus-reinforcer contingencies determine resistance to change, the component with supplementary DRO reinforcement exhibited (relative to baseline and compared with the other component) enhanced resistance to a disrupting stimulus, despite lower rates of response engendered by the DRO arrangement.

The resistance to change effects predicted by Behavioural Momentum Theory extend convincingly across several species and experimental procedures that utilise between-groups and within-subjects designs. Sufficient data have accumulated for Nevin to extend behavioural resistance theory beyond the limits of ordinal, or qualitative prediction, and to develop an integrative and quantitative model (Nevin, 1992a). This model is based on an analysis of data from studies using single-key multiple schedules (Nevin et al, 1983; Nevin et al, 1990; Shettleworth and Nevin, 1965; Nevin, 1974, 1992b), multiple chained serial schedules (Nevin, Mandell, and Yarensky, 1981; Nevin, 1984; Nevin et al, 1987; Nevin et al, 1990), and two-key multiple concurrent schedules (Nevin et al, 1990).

1.2.5. A quantitative model.

Underlying the quantitative model for resistance to change is an analysis of stimulus-reinforcement contingency based on an account of autoshaped key pecking developed by Gibbon (1981). This account proposes that the strength of a stimulus-reinforcer contingency is a function of the ratio of the average reinforcer rate in the presence of a CS to the session average reinforcer rate. This ratio can be expressed as rc/rs (where rc is reinforcer rate in the presence of the CS and rs is the average reinforcer rate for the entire session). Not only does this ratio allow the ordinal prediction of resistance to change (e.g. Nevin, 1992b), but it facilitates the development of a more sophisticated and quantitative model for resistance to change.

If an operant's resistance to change is determined by the strength of the associated stimulus-reinforcer contingency, then Gibbon's formulation of this contingency suggests that the ratio expressing relative resistance to change (m1/m2) in the standard behavioural momentum experimental paradigm should depend upon the ratio of stimulus-reinforcer contingencies in the two components. That is, as a general starting point,

$$\frac{m1}{m2} = f\left(\frac{rc1/rs}{rc2/rs}\right).$$

In multiple schedules, the average reinforcement rate for the session (rs) is the same for each component and the resistance ratio is therefore some function of the ratio rc1/rc2.

Nevin (1992a) has re-analysed resistance to change data from studies that employed a single-key multiple schedule procedure (Nevin et al, 1983; Nevin et al, 1990; Shettleworth and Nevin, 1965; Nevin, 1974; Nevin, 1992b). These data are summarised by Nevin (1992a,

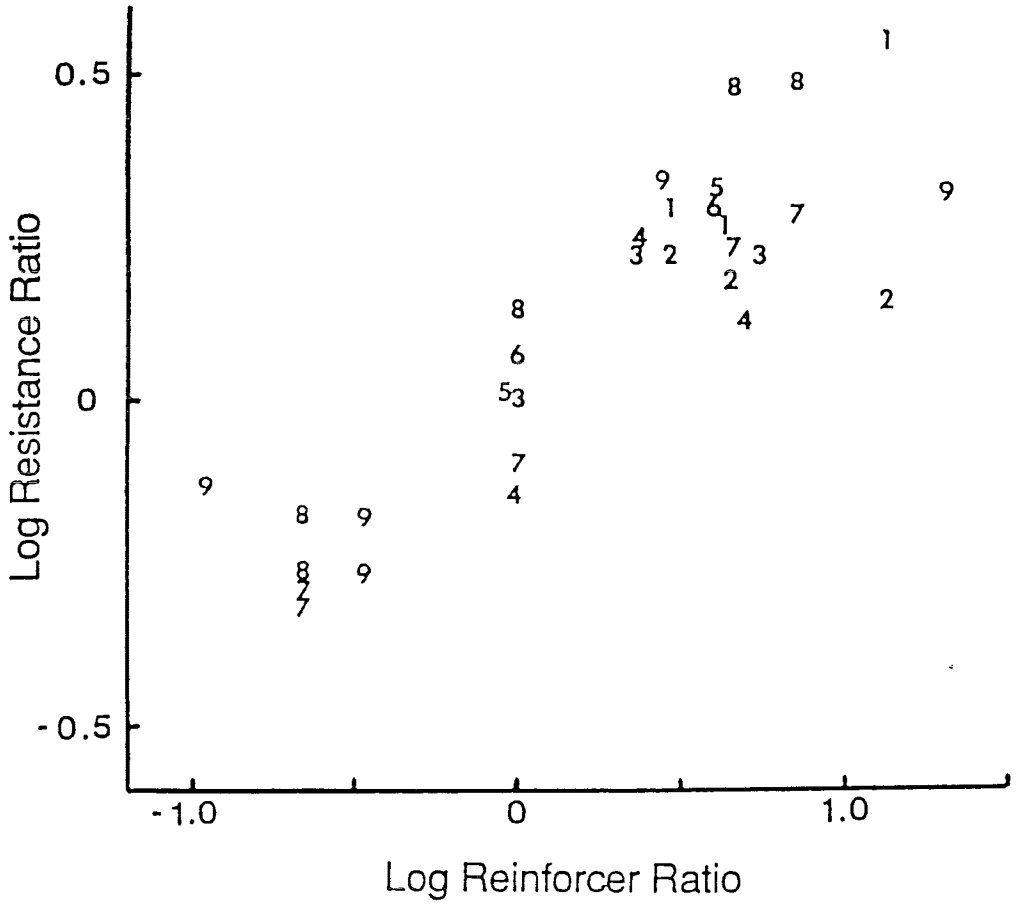

Figure 1.1. Relative resistance plotted as a function of relative reinforcement for existing single-key multiple schedule resistance studies (reproduced from Nevin 1992a, Figure 2). Both variables are expressed in logarithmic form and data points represent group data for different experiments and methods for evaluating resistance. Data are keyed as follows: 1: dark-key food; 2: extinction; 3: prefeeding; 4: extinction; 5: prefeeding; 6: extinction; 7: prefeeding; 8: extinction; 9: various disruptors.

Figure 2) and reproduced here as Figure 1.1, and suggest that log resistance ratios are related to log reinforcer ratios by a power function with an exponent of approximately 0.35 (Nevin, 1992a, p 305). Although these data are obtained across several studies that employed different pigeons, Nevin argues that they are consistent "to a respectable first approximation", and that there is no evidence of systematic deviations between experiments. While this is true for several studies, there are nevertheless some notable (but non-systematic) inconsistencies deserving of a closer analysis. These will be examined in a subsequent section.

When data from resistance to change studies utilising multiple chained and serial schedules (Nevin et al, 1981; Nevin, 1984; Nevin et al, 1987; Nevin et al, 1990) are treated in the same fashion as single-key studies, similar results are obtained, with the same relationship between log resistance and log reinforcer ratios being evident (Nevin, 1992a, Figure 3, page 307). However, in contrast to single-key procedures, chained and serial schedules employ different stimuli within components, requiring that the model explicates resistance to change effects by treating key position as the important stimulus element associated with stimulus-reinforcer contingencies (ibid, p 306).

Nevin's integrative and quantitative model for resistance to change summarises these data sets and takes the form of an expression describing the relative resistance to change of two multiple schedule components in terms of the components' relative reinforcer rates (rc1 and rc2) and their correlation with key location (rk1 and rk2). Where the sensitivity of resistance ratios to reinforcement ratios is represented by exponents a and b, the expression takes the form

$$\frac{m1}{m2} = \left(\frac{rc1/rs1}{rc2/rs2}\right)^{a} \times \left(\frac{rk1/rs1}{rk2/rs2}\right)^{b}.$$

When applied to single-key multiple schedule performances, rs1 = rs2 and rk1 = rk2. The equation simplifies to $m1/m2 = (rc1/rc2)^{a}$, or in log form, $\log(m1/m2) = a.\log(rc1/rc2)$. When a is 0.35, this equation is consistent with the data presented by Nevin for single-key multiple schedules (Figure 1.1), and provides an adequate description of the main trend.

In multiple chained and serial schedules where initial links are equivalent, rc1 = rc2 and rs1 = rs2. Accordingly, the general model simplifies to m1/m2 = (rk1/rk2)^{b} or log(m1/m2) = b.log(rk1/rk2). This is consistent with Nevin's presentation of the data for these schedules (1992a, Figure 3) and again, adequately describes the main trend.

In general, the integrative model for resistance to change appears quantitatively consistent with the data from numerous studies. Although there is considerable variability within the overall data (Nevin, 1992a, page 309), the absence of systematic variation across different experiments, procedures and behavioural disruptors lends credibility to the proposed quantitative model. However, there are a number of difficulties for the generality of the quantitative model for resistance to change. These are discussed by Nevin in his recent review and meta-analysis (1992a, pp 310-312) and relate to the Partial Reinforcement Effect, the use of pharmacological agents as behavioural disruptors, and the relationship between behavioural momentum research and the Quantitative Law of Effect. Of these, the Partial Reinforcement Effect is most relevant to the present work.

1.2.6. Behavioural momentum and the Partial Reinforcement Effect.

On the face of it, the Partial Reinforcement Effect poses a significant problem for Behavioural Momentum Theory because it appears to contradict the general and persistent finding from momentum research, that responses associated with higher values of reinforcement exhibit the most resistant to change. However, the Partial Reinforcement Effect is observed in relation to the total number of responses emitted during the course of extinction. While Behavioural Momentum Theory is also concerned with persistence in the face of extinction, this is measured in quite different terms.

In contrast to traditional PRE research, behavioural momentum studies use the slopes of extinction curves, relative to baseline, as measures of resistance to extinction. Simply measuring the number of responses during a criterion period fails to dissociate the level of baseline responding from the rate of decrease in responding during extinction (Nevin, 1988, p 48). For example, in Boren's 1961 study intermittently reinforced performances exhibited

higher baseline response rates than a continuously reinforced performance. Using the number of responses emitted during extinction as a measure of resistance is misleading because even when responses reduce at the same rate relative to baseline, more responses are emitted during extinction in a component with a higher baseline response level.

To demonstrate the validity of Behavioural Momentum Theory in the face of the PRE, Nevin (1988) re-analysed five free operant studies (Jenkins, McFann and Clayton, 1950; Jenkins and Rigby, 1950; Wilson, 1954, Jenkins, 1978; and Boren, 1961) which demonstrated the orthodox Partial Reinforcement Effect, and where extinction data enabled comparison of CRF responding with that maintained by partial reinforcement. Instead of measuring free-operant partial reinforcement effects as total responses per unit time, extinction data were plotted as a proportion of response rate in the first session of extinction, an approximation of the standard behavioural momentum experiment.

When the Partial Reinforcement Effect data are re-analysed in this way, a clear pattern of results emerged, with interesting differences between resistance measures obtained early in training compared with those taken after more prolonged baseline performances. For operants assessed early in training (Jenkins, McFann and Clayton, 1950; Jenkins and Rigby, 1950; Wilson, 1954) there is a clear Partial Reinforcement Effect in terms of resistance slopes, with CRF responses demonstrating less resistance to extinction than partially reinforced responses. However, for operants with a more established reinforcement history (greater than about 250 reinforcers) the results are consistent with Behavioural Momentum Theory. That is, in terms of resistance slopes, CRF responding was more resistant to extinction than responses receiving intermittent reinforcement (Wilson, 1954, Jenkins, 1978; Boren, 1961).

Nevin accounts for the discrepancy between these stages of training by suggesting that there is a "gradual increase in resistance to change as training progresses" (1988, p 52). This is consistent with Behavioural Momentum Theory, because if mass accrues as a function of reinforcement, this must take time to occur. The lack of the effect predicted by Behavioural Momentum Theory in early training could well be ascribed to this factor. However, this does not explain why the Partial Reinforcement Effect observed in early training should occur at all, and the implications of this are of interest within the context of a subsequent argument.

The PRE and Discrete Trials.

The relationship between Behavioural Momentum Theory and the Partial Reinforcement Effect is made more complex when an analysis of discrete trials procedures is considered. Nevin (1988) demonstrated that CRF components are more resistant to change in respect of well established free-operant responses, but partial reinforcement effects have normally been studied in between-group discrete-trials runway procedures (Nevin, 1992a, p 310). Because these typically employ brief training regimes to produce a standard Partial Reinforcement Effect, Nevin (1989) performed a within-subjects discrete trials replication using pigeons trained on 2,000 reinforcers before resistance testing was initiated. The results from Nevin's 1988 study suggest that well-trained responses do not demonstrate a Partial Reinforcement Effect. When relative resistance to change was assessed using prefeeding or dark-key food, this effect was not observed. However, in an interesting contrast, when extinction was applied as a disruptor, resistance was higher on the partially reinforced key than that receiving continuous reinforcement, thus displaying the typical Partial Reinforcement Effect. This is not consistent with Behavioural Momentum Theory, and Nevin concludes that extinction after partial reinforcement in discrete trials has "special properties that remain to be analysed" (1992a, p 310). This phenomenon is also of interest within the context of the following discussion.

In general however, the Partial Reinforcement Effect does not pose the sort of overwhelming difficulty for Behavioural Momentum Theory that a prima facie examination suggests. Traditional Partial Reinforcement Effect research and behavioural momentum studies are concerned with quite different measures of persistence, and it appears that well-trained responses resist extinction in a fashion consistent with Behavioural Momentum Theory. Only 'immature' free operant responses, or those produced in a discrete trials procedure and tested with extinction, demonstrate a Partial Reinforcement Effect in terms of resistance slopes. Nevertheless, these two situations comprise interesting exceptions to a general rule, and will be discussed within the context of the rationale for the present study.

1.3. RATIONALE FOR THE PRESENT STUDY.

1.3.1 Overview.

Behavioural Momentum Theory is an account of relative resistance to change that is in general agreement with a large body of empirical evidence. When applied to single-key multiple schedules, the quantitative model for resistance to change provides a reasonable summary of existing data. Figure 1.1 reproduces Nevin's (1992a, Figure 2) summary of resistance to change data from existing single-key multiple schedule studies and shows resistance ratios plotted as a function of relative reinforcement. Compared to a single linear function with a slope of 0.35, these data are quite variable. This might be the effect of using data from different experiments with different subjects, but it may be the result of some systematic but concealed effect.

Data from previous single-key resistance studies are open to several interpretations which are illustrated in Figure 1.2. First, in the left-most panel, data in Figure 1.1 can be represented by a single resistance function with an exponent of approximately 0.35, with variability being attributed to the use of different subjects across different experiments. This is consistent with Behavioural Momentum Theory and is the position adopted by Nevin. Second, as the middle panel in Figure 1.2 shows, the single-key data in Figure 1.1 could represent resistance functions with the same slope but different y-intercepts, reflecting bias in relative resistance to change. A third, more interesting possibility is shown in the right-most panel in Figure 1.2. This shows a number of resistance functions where the exponents vary systematically. As the following discussion will show there are a number of reasons to expect that mass ratios and the slopes of resistance functions relating relative resistance to relative reinforcement might vary when different types and magnitudes of disruptor are used to measure relative mass. This is not consistent with Behavioural Momentum Theory or with the quantitative model for resistance to change.

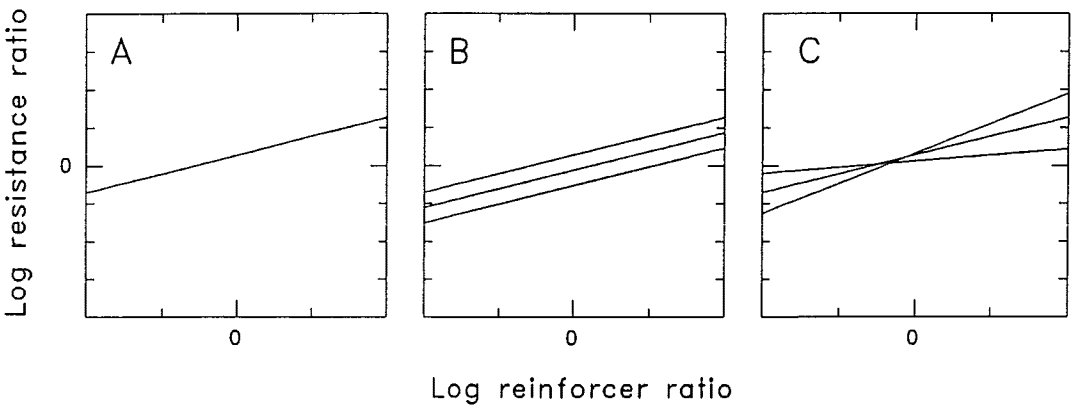

Figure 1.2. Three possible interpretations of the single-key multiple schedule data summarised by Nevin and presented in Figure 1.1. Data presented by Nevin can be viewed in terms of a single linear function (Panel A), parallel functions (Panel B), or functions with systematically different slopes (Panel C).

Nevin's summary of single-key multiple schedule resistance data is open to several interpretations. However, it is difficult to know whether Figure 1.1 really does conceal systematic effects that are incompatible with Behavioural Momentum Theory because the data are group averages drawn from different experiments that used different subjects. To test the assumption that mass ratios remain invariant when different types and magnitudes of disruptor are used, there is a clear need for a within-subjects study using a variety of disruptor types and magnitudes.

1.3.2 Type and magnitude of force.

Different magnitudes of disruption could be expected to produce mass ratio variance because this is predicted by the Quantitative Law of Effect. The Quantitative Law of Effect (Herrnstein, 1970, 1974) describes the hyperbolic relationship that is typically observed between response rate and rate of reinforcement (e.g. Catania and Reynolds, 1968). According to Nevin (1992b), when this model is applied to multiple schedule resistance research, the effects of disruption can be construed as an increase in the value of extraneous reinforcement (R_0). Consistent with

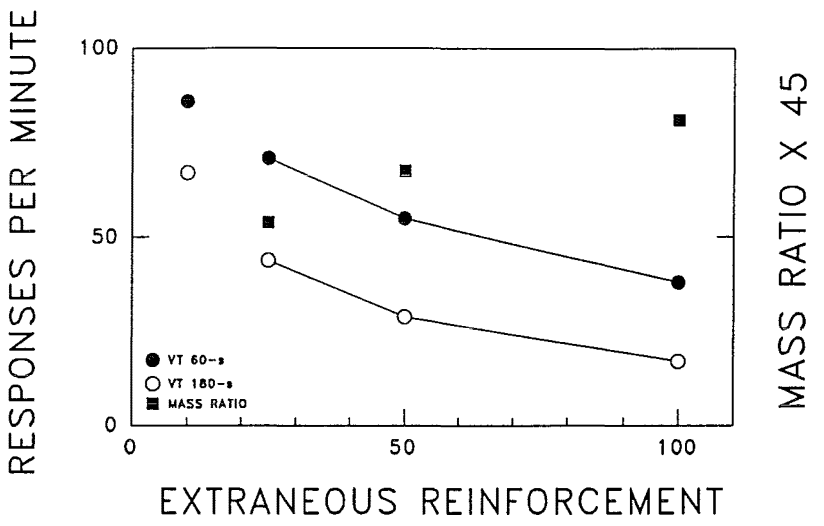

Figure 1.3. Response rates and mass ratios, in two hypothetical multiple schedule components, plotted as a function of extraneous (R_o) reinforcement. Circles represent response rates during baseline conditions ($R_o = 10$) and subsequent sessions of disruption (increasing values of R_o), as predicted by the Quantitative Law of Effect. Mass ratios, calculated as the ratio of the proportions of baseline responding in each component, are represented by filled squares and have been multiplied by 45 to maintain compatibility with the vertical axis. Predictions were obtained using the formula $\mathbf{P = kR / R + R_o}$ for each component with **k** set at 100 responses/minute.

Behavioural Momentum Theory, analysis of resistance to change procedures in terms of the Quantitative Law of Effect predicts that the richer of two multiple schedule components, will, as a proportion of baseline responding, reduce less than the leaner component.

Interestingly though, the Quantitative Law of Effect also predicts that as the magnitude of disruption increases, so will the size of the resultant mass ratios. Figure 1.3 shows the effects of increasing the magnitude of disruption on two components of a multiple schedule, as predicted by the Quantitative Law of Effect. As the value of R_0 in both components increases, response rates in the components reduce. In contrast, mass ratios, defined as the ratio of the proportion of baseline responding in each component, increase.

Extinction and other forces.

While the Quantitative Law of Effect predicts that mass ratios will vary as a function of disruptor magnitude, some features of extinction suggest that different types of disruptor could also produce variation in mass ratio.

Extinction could be expected to produce smaller mass ratios than other disruptors for several reasons. First, extinction involves the discontinuation of reinforcement for some previously reinforced response, but where components differ in the value of reinforcement they receive, this reduces reinforcement more for a rich component than the leaner one. This implies that extinction is a larger force when applied to a rich component than a lean one. The result of this should be smaller mass ratios and shallower resistance functions than would be obtained using a disruptor that constituted the same force for each component. However, this argument depends on viewing extinction in terms of absolute values of reinforcement. Viewed proportionally, extinction reduces reinforcement by one hundred percent in both components, and could thus be said to comprise the same force for each component.

There is however, a second feature of extinction consistent with the idea that this procedure should produce smaller mass ratios than other disruptors. Considered in terms of generalisation effects (Guttman and Kalish, 1956), extinction involves a larger generalisation decrement in a component with a high rate of reinforcement than in a component with a low

rate of reinforcement. Because long strings of unreinforced responses are not a stimulus feature in components maintained on high reinforcer rates, but are a familiar element in a less frequently reinforced component, extinction involves a larger disruption of the stimulus conditions in a component maintained on higher rates of reinforcement. This also implies that extinction constitutes a larger force for rich components than lean ones, and predicts that in resistance studies, extinction should produce smaller mass ratios and shallower resistance functions than other types of disruptor.

Finally, there is another reason to expect differences between extinction and other disruptive forces. If forces are defined in absolute terms, extinction involves reducing reinforcement more in one component than in another, and should produce small mass ratios as a result. This is not expected if forces are defined in proportional terms. However, if forces are defined in proportional terms, then dark-key food and possibly prefeeding should produce larger mass ratios than extinction, because in proportional terms these procedures involve more alternative food for a lean component than a rich one.

The disrupting effect of dark-key food applied during the inter-component interval of a multiple schedule (and possibly prefeeding) can be construed in terms of negative behavioural contrast. Behavioural contrast is an established phenomenon associated with multiple schedules (Reynolds, 1961). When changes in behaviour are effected in one component of a multiple schedule, a corresponding but converse change in behaviour is observed in the other. Thus, where one component is placed in extinction, a decrease in response rate is observed in that component. For the other component however, response rate typically increases, an effect referred to as positive contrast. The opposite effect, negative contrast, is a decrease in response rate that occurs in one component when reinforcement is increased in the other. The disruptive effects of dark-key food introduced during the intercomponent interval can be viewed as negative contrast in the two other components. However, if forces are construed proportionally, then dark-key food is a larger force relative to lean components because dark-key reinforcers represent a larger proportion of reinforcement in lean components than in rich ones. This predicts that dark-key food will produce larger mass ratios than extinction. The same argument can be extended to the effects of prefeeding. If prefeeding exerts its disruptive

effects through the mechanism of behavioural contrast, then construed in proportional terms, this disruptor should, like dark-key food, produce larger mass ratios than extinction.

In summary, there are conceptual reasons to expect that different types and magnitudes of disruptor should produce mass ratio variance in resistance studies. Although there is no systematic evidence of this in Nevin's (1992a, Figure 2) summary of single-key multiple schedule resistance studies, some evidence from individual studies is consistent with the idea that extinction produces smaller mass ratios than other disruptors.

1.3.3 Empirical evidence.

There is one study (Nevin et al, 1983) in which extinction clearly produced smaller mass ratios than another disruptor, dark-key food. This study compared the disruptive effects of dark-key food and extinction across a range of relative reinforcer rates. Reinforcer ratios varied between 3.1 and 12.9 and resistance ratios varied between 2.5 and 8.3 for dark-key food, but between 1.5 and 1.8 for extinction. When Nevin (1992a) re-analysed these data using an alternative computation, the disparity with dark-key food became even more pronounced. Resistance ratios obtained with extinction actually decreased as a function of increases in reinforcer ratio (see data points labelled "2" in Figure 1.1).

These data are consistent with the idea that extinction should produce smaller mass ratios than other disruptors. However, this result has not been systematically reproduced. What follows is more tangential, but provides some evidence in support of the view that extinction constitutes a larger force for richer components than lean ones, and should therefore produce smaller mass ratios than other disruptors.

Extinction and the Partial Reinforcement Effect.

Nevin's response to the Partial Reinforcement Effect is based on the observation that in terms of extinction slopes, this effect only occurs early in training, prior to about 250 reinforcements. After more prolonged training the opposite effect is observed, with continuously reinforced responding demonstrating most resistance to the effects of extinction (Nevin, 1988).

This pattern of results is consistent with the notion that extinction may be a greater disruptive force in relation to rich components because if extinction was the same force in two differentially reinforced components, it is hard to see why a Partial Reinforcement Effect should be observed early in training. Resistance to change develops as a function of cumulative reinforcement (Nevin, 1988, p 52), and early in training there should be little difference in behavioural mass between the components. This being so, the application of equal forces should reveal little difference between behavioural masses. The fact that continuously reinforced behaviour is disrupted more (relative to baseline) than intermittently reinforced responding early in training strongly suggests that the force is greater on this component than on the other. The reverse pattern, observed in later training, is also consistent with this interpretation because at this later stage continuously reinforced responding has acquired considerably more mass than the lean component. Even though the force is greater on the continuously reinforced component, its enhanced resistance to change means that it is disrupted less than the other component (which is affected by a smaller force, but has considerably less mass resisting it). These data are consistent with the idea that extinction does not exert the same force on each component in a multiple schedule when these are maintained by different rates of reinforcement.

Further data reported in the same paper indicate that this effect might result from differences in generalisation decrement between components. In a 'confirming experiment' (1988, p 52-53) Nevin examined the effects of extinction on continuously reinforced and partially reinforced components in a within-subjects design using pigeons. The important

feature of this experiment was that the procedure endeavoured to equalise the decremental effects of extinction by signalling its introduction. Another unusual feature was that extinction conditions were repeated daily and the effects of this disruption compared as training developed. Effects obtained late in training were clearly consistent with Behavioural Momentum Theory in that the CRF component was most resistant to the effects of extinction. However, early in training there was no evidence of systematic differences in resistance between rich and lean components. This provides some evidence that when generalisation decrements are equalised, the Partial Reinforcement Effect is not observed even in early training and suggests that it is a differential generalisation decrement that makes extinction unequal in its effects at this stage of training.

This result is suggestive but not conclusive. The procedure was unusual, it is not clear that generalisation decrements were equalised as intended, and the results noted in early training were fairly variable. In addition only three birds were used and replication is needed. Nevertheless, there is at least some support for the argument that the Partial Reinforcement Effect observed early in training can only occur if extinction exerts a greater force on the richer component than its leaner counterpart. The apparent lack of this effect where generalisation decrements may have been equalised suggests that this may result from differential generalisation effects. Thus, Nevin's 1988 paper provides some evidence that extinction involves a larger force for a more frequently reinforced component than a lean one, and therefore, that this procedure should produce smaller mass ratios than other disruptors.

Discrete trials and the Partial Reinforcement Effect.

Nevin's findings relating to the Partial Reinforcement Effect within the context of discrete trials performance (Nevin, 1992b, p 310) are also consistent with the idea that extinction should produce smaller mass ratios than other disruptors. To reiterate, Nevin established two well-trained differentially reinforced responses in a discrete trials procedure. When disrupted using dark-key food or prefeeding, responding was more persistent on the continuously reinforced key than on a partially reinforced key. However, a notable contrast was that during extinction,

the partially reinforced response was more persistent than the continuously reinforced performance. To account for this result, Nevin (1992a, p 310) has tentatively proposed an interpretation in terms of a recent foraging analysis (Mellgren and Elsmore, 1991). A more parsimonious interpretation is that extinction exerts a disproportionately large force on the continuously reinforced component. If extinction represented the same force for each component, it would be reasonable to expect that the results obtained using dark-key food and prefeeding would have been replicated. This was not the case and greater disruption of the CRF component is again compatible with the view that extinction is a larger force in rich components than lean ones, and that it should produce small mass ratios as a result.

Extinction as a reduction in rate of reinforcement.

Finally, the same conclusion is suggested in an experiment (Harper and McLean, 1992, Experiment 2) which compared relative resistance to change in components that differed only in respect of reinforcer duration. In this experiment, disruptive force was applied in the unusual form of a change in the rate of reinforcement. Interestingly, no mass differentials were revealed. The result is enigmatic because their Experiment 1, using the same subjects and reinforcer magnitudes, revealed a clear mass differential when responding was disrupted with dark-key food. A change in reinforcer rate should function as a disruptive force in much the same way as extinction because in a proportional sense, changes in reinforcer rate are continuous with extinction. Thus, in Harper and McLean's second experiment, a force continuous with extinction should have revealed the mass differential already demonstrated using dark-key food.

However, this apparently enigmatic finding is consistent with the idea that extinction is larger force in rich components than lean ones. If the richer component in Harper and McLean's second experiment had been affected by a larger force than the lean one, both components might have changed about the same amount relative to baseline. Thus, the failure of this experiment to obtain differential resistance might be due to the force differential implicit in a disruptor that is continuous with extinction. If disruption continuous with extinction

involves a larger force for a rich component than a lean one, then the same should be true of extinction itself.

Interestingly, if the lack of effect observed in Harper and McLean's second experiment was due to the application of different forces, this occurred independently of a difference in generalisation decrement between the components, since these differed in size, not frequency of reinforcers. This supports the notion that absolute values of reinforcement are important features of the extinction procedure.

1.3.4 Summary and implications.

Conceptual issues, and findings from several studies, suggest that mass ratios may vary systematically when different types and magnitudes of disruptor are used to measure relative resistance. The Quantitative Law of Effect predicts that mass ratios should increase as larger magnitudes of disruption are applied. Different types of disruptor may also produce mass ratio variance. If forces are construed in absolute terms, extinction entails more force for a richer component than a lean one, thus predicting smaller mass ratios for extinction than other disruptors. Alternatively, if forces are construed in proportional terms, dark-key food, and possibly prefeeding entail more force for leaner components than rich ones, thus predicting larger mass ratios for these procedures than for extinction. Finally, various empirical results are consistent with the idea that extinction is a larger force in richer components than lean ones, and should therefore produce smaller mass ratios than other procedures.

Thus, although Nevin's summary of single-key resistance studies (Figure 1.1) does not reveal systematic mass ratio variance, there are a number of reasons to expect that mass ratios and the slopes of resistance functions should vary when different types and magnitudes of disruptor are used. Further, Figure 1.1 could easily conceal systematic variations in mass ratio because it contains group-average data obtained from different studies and different subjects. Accordingly, the present work seeks within-subjects confirmation of the assumption that mass ratios will be invariant when different types and magnitudes of disruption are applied.

1.4 THE PRESENT STUDY.

Nevin (1992a, Figure 2) has recently presented data from a number of single-key multiple schedule studies that used rate and magnitude of reinforcement to establish differential resistance to change in two components. However, only one study (Nevin, 1974) has used delayed reinforcement to investigate resistance effects, and this used just two birds in a two-key procedure. It is not, therefore, included in Nevin's summary of single-key studies.

Furthermore, there is some evidence that the sensitivity of relative resistance to relative reinforcement may be lower for delayed reinforcement than for other parameters of reinforcement. In Nevin's (1974) experiment using delayed reinforcement, resistance differentials were produced most clearly when immediacy ratios were 1:9. When ratios were 1:3, resistance effects were more equivocal. In contrast, studies using reinforcer rate (e.g. Nevin, 1974) and magnitude (Harper and McLean, 1992), have obtained clear resistance differentials when reinforcer ratios were 1:3. Thus, there is preliminary evidence that relative resistance is less sensitive to relative reinforcer immediacy than to relative rate or magnitude of reinforcement. Because there are no resistance data for single-key studies using delayed reinforcement, and because the sensitivity of relative resistance obtained with relative reinforcer immediacy may be lower than with other reinforcement parameters, the present study investigates the effects of delayed reinforcement in a systematic replication and extension of previous behavioural momentum research (Nevin, 1974, 1992a, 1992b; Nevin et al, 1983).

Another reason to use delayed reinforcement has to do with the idea, discussed previously, that extinction comprises a larger force for a rich component than a lean one. This predicts that extinction will produce smaller mass ratios than other disruptors. However, establishing resistance differentials with delayed reinforcement means that extinction discontinues the same rate of reinforcement for each component and the generalisation decrements should therefore be the same for each component. Nevertheless, as Harper and McLean's results suggest, it is still possible that extinction constitutes a different force for two components that are maintained with the same rate, but different overall values of reinforcement.

Finally, the previous section discussed the idea that mass ratios might be expected to vary systematically when different types or magnitudes of disruption are used. Nevin's summary of existing studies (Figure 1.1) does not allow these issues to be addressed because it is difficult to tell whether the variability evident in this figure is the result of systematic variation or the use of data obtained across different studies and with different subjects. Accordingly, the present study examines the disruptive effects of different types and magnitudes of disruption in a within-subjects single-key multiple schedule procedure, using delayed reinforcement as a determinant of differential resistance to change. In addition, different strengths of prefeeding and dark-key food are employed. This work also includes a reversal of baseline conditions and a repeat of disruptors. This means that the slopes of the resistance functions (relating relative resistance to relative reinforcement) can be measured, thus allowing a full comparison with Figure 2 in Nevin 1992a (reproduced here as Figure 1.1).

2.1 EXPERIMENT 1.

According to Behavioural Momentum Theory, mass ratios and the slopes of resistance functions should not vary systematically when relative resistance to change is assessed using different types or magnitudes of disruption. This requirement is implicit in the quantitative model for resistance to change and is also inherent within the logic underlying the experimental method employed in resistance to change research. Mass ratios are measured in terms of the ratio of change in responding that occurs as the result of disruption. This measure derives from Newton's second law. When f1 = f2, m1/m2 = Δv2/Δv1 and this provides the basis for measuring relative mass within the context of multiple schedule resistance to change research. The logic of this approach requires that the same amount of force is applied to each component (i.e. f1 = f2), but the type and magnitude of the disruptive force should be irrelevant. It follows, therefore, that mass ratios and the slopes of resistance functions should remain invariant across conditions where the same performances are assessed using different types or magnitudes of disruption.

Experiment 1 tested this prediction by comparing the disruptive effects of dark-key food, prefeeding, extinction, and a concurrent distracting stimulus in two multiple schedule components which differed in reinforcer immediacy. In addition, varying magnitudes of prefeeding and dark-key food were tested. A reversal procedure was employed to enable comparison with data from other single-key studies (Nevin 1992a, Figure 2) and to determine the slopes of the resistance functions relating log resistance ratio to log reinforcer immediacy ratio for each disruptor. Previous results suggest that resistance functions should have a slope of approximately 0.35 (Nevin 1992a, p 305), a value that should not vary systematically as a function of disruptor type or magnitude.

METHOD.

Subjects.

Four adult homing pigeons, with extensive experience in multiple schedules, were maintained between 80 and 85% of their free-feeding weights. Water and grit were available continuously in their home cages and post-experiment supplementary feeding with mixed grain ensured that body weights were maintained within the required range.

Apparatus.

The experiment was conducted using four operant chambers, each with dimensions approximating 34 cm by 34 cm by 32 cm. An interface panel comprised one wall of each chamber and featured a food hopper mounted centrally, 6 cm above floor level, and three response keys mounted 21 cm above the floor and 9 cm apart. Only the centre key was employed and this was illuminated with red or green light in multiple schedule components, or darkened during 30 second inter-component intervals and during the delay intervals associated with reinforcement. Key pecks extinguished response-key illumination for 0.05 s and produced reinforcement according to a VI 90-s schedule (Fleshler and Hoffman, 1962) in which reinforcement was 3-s access to wheat after either 1-s or 8-s delay. During reinforcement the response key remained dark and the wheat hopper was illuminated with white light. A ventilation fan at the rear of the chamber provided masking noise, and a white houselight was mounted in the top-right corner of the interface panel. Schedules were controlled, and data were recorded, by an IBM AT-compatible computer operating MED-PC software.

Procedure.

Experimental sessions were conducted daily at approximately the same time and consisted of twenty-eight multiple schedule components, each of 60-s duration excluding time allowed for delays and reinforcement. Components were presented equally often and in random order, and each component was preceded by a 30-s dark-key period, normally in extinction. During initial training, reinforcement delays were faded in over 45 sessions and an additional 31 baseline

Table 1.

Order of conditions in Experiment 1 showing the number of sessions in each condition. Phase 2 comprises a reversal of the reinforcer delays in Phase 1.

Condition	Description	Number of sessions
Phase 1 (1 second versus 8 seconds delay in components 1 and 2 respectively).		
1	Baseline	31
2	Prefeeding 10%	1
3	Baseline	16
4	Prefeeding 5%	1
5	Baseline	18
6	Prefeeding 10%	1
7	Baseline	21
8	Prefeeding 5%	1
9	Baseline	30
10	Extinction	9
11	Baseline	31
12	Dark-key food VT 30-s	10
13	Baseline	30
14	Dark-key food VT 60-s	12
15	Baseline	30
16	Houselight (B2-4)	5
	Prefeeding 10% (B1)	1
Phase 2 (8 seconds versus 1 second delay in components 1 and 2 respectively).		
17	Baseline	51
18	Prefeeding 5%	1
19	Baseline	28
20	Prefeeding 10%	3
21	Baseline	20
22	Dark-key food VT 60-s	10
23	Baseline	21
24	Dark-key food VT 30-s	10
25	Baseline	20
26	Extinction	9

sessions ensured that responding had stabilised prior to any resistance testing. After initial training the experiment featured two phases. In Phase one, red component responses obtained reinforcers with 1-s delays and green component responses obtained reinforcers with 8-s delays. This was reversed in Phase two and the resistance tests repeated. All resistance tests were preceded by an extended period of baseline training, usually 30 days, although briefer periods were employed after single-session disruptions with prefeeding and in the latter stages of the experiment. The final ten days of each baseline period provided data against which the effects of disruption were measured.

Resistance to dark-key food was tested by introducing 3-second food reinforcers during the inter-component interval according to either a VT 30-s or a VT 60-s schedule. Prefeeding conditions provided subjects with either 5% or 10% of their body weight in mixed grain 50 minutes prior to the experimental session. The effects of a concurrent distracting stimulus were assessed by illuminating the houselight continuously during red and green multiple schedule components, while extinction entailed the elimination of all scheduled reinforcers and the associated delays. Subjects underwent the same order of exposure to the various conditions, with the exception of Bird B1 which was introduced into the experiment in Condition 8 to replace a subject that failed to respond consistently to delayed reinforcement. Table 1 shows the order of conditions for Experiment 1 and the number of sessions in each condition.

RESULTS AND DISCUSSION.

Consistent with the established effects of delayed reinforcement on choice (Baum and Rachlin 1969; Brownstein, 1971), and unlike some previous results using delayed reinforcement in multiple schedules (e.g. Nevin, 1974, p 398), the subjects in Experiment 1 consistently distributed their responses in favour of the component with the shortest reinforcer delay. In Figure 2.1, log response ratios (obtained during baseline conditions) are displayed as a function of log reinforcer immediacy ratios. The slope of the fitted regression line is given in parentheses in each panel, and indicates the sensitivity of relative response rates to relative reinforcer immediacy. Although sensitivity was generally low (averaging 0.1), responding was sensitive to the effects of delayed reinforcement for all subjects.

Relative resistance to change was measured in two related ways for each disruptor. First, mass ratios were obtained using the average proportion of baseline responding (APOB) for each component during the disruption condition. Proportions of baseline responding were derived for each session in the disruption conditions by dividing the response rate for each component by the average response rate for that component during the last ten days in the previous baseline training condition. The ratio of the average of these proportions (i.e. APOB Component 1/APOB Component 2) provided the measure of relative mass. To ensure a valid

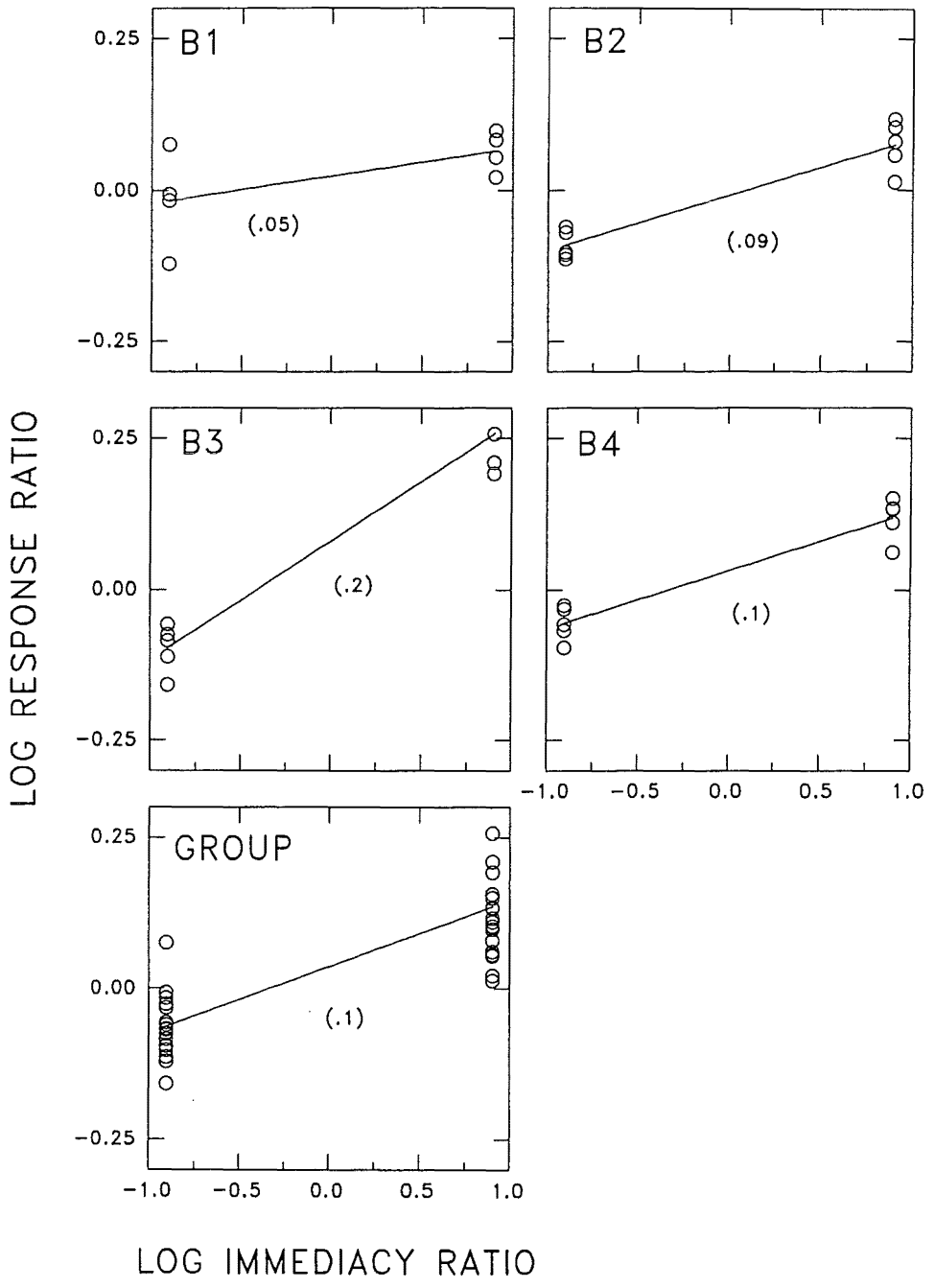

Figure 2.1. Log response ratios in baseline plotted as a function of log reinforcer immediacy ratios in Experiment 1. The slopes of least-squares regression lines are given in parentheses in each panel. Note that vertical and horizontal axes are unequal.

comparison between the two phases of the experiment, each disruptor was evaluated using data taken from the same number of days in each experimental phase. That is, if average proportions of baseline were obtained using data from the first six days of disruption in Phase one, data from the first six days were also used in Phase two. Table 2 summarises the resistance ratios obtained in Experiment 1 and expresses these in logarithmic form.

Table 2.

Log mass ratios derived using the ratio of average proportion of baseline for each component in Experiment 1.

Phase 1	B1	B2	B3	B4
PF 5%	0.150	0.086	0.198	0.108
PF 10%	0.161	0.288	0.361	0.543
VT 60-s	0.136	0.096	-0.081	0.056
VT 30-s	0.191	0.202	-0.046	0.009
EXT	0.238	0.122	0.091	0.113
Phase 2				
PF 5%	0.024	0.040	0.069	0.022
PF 10%	-0.026	-0.142	0.120	0.198
VT 60-s	-0.020	-0.049	0.089	-0.019
VT 30-s	-0.129	-0.159	-0.043	-0.101
EXT	-0.270	-0.159	-0.198	-0.087

In addition to using resistance ratios as a measure of relative mass, the slopes of the resistance functions relating log resistance ratios to log reinforcer immediacy ratios were ascertained. Thus, consistent with Figure 2 in Nevin 1992a, the logarithms of mass ratios were plotted for each disruptor in the two phases of the experiment and the slopes of the functions obtained in this way provided a second measure of relative mass.

Prefeeding.

Figure 2.2 shows resistance to the effects of prefeeding for each component in both phases of Experiment 1. Response rate, expressed as proportion of baseline responding in the two components, is plotted as a function of the amount prefed. In both phases of the experiment filled circles represent the component with 1 second delay and unfilled circles the component with 8 seconds delay. In Phase one, there is a clear differential resistance effect for both strengths of prefeeding. Consistent with Behavioural Momentum Theory, the component with

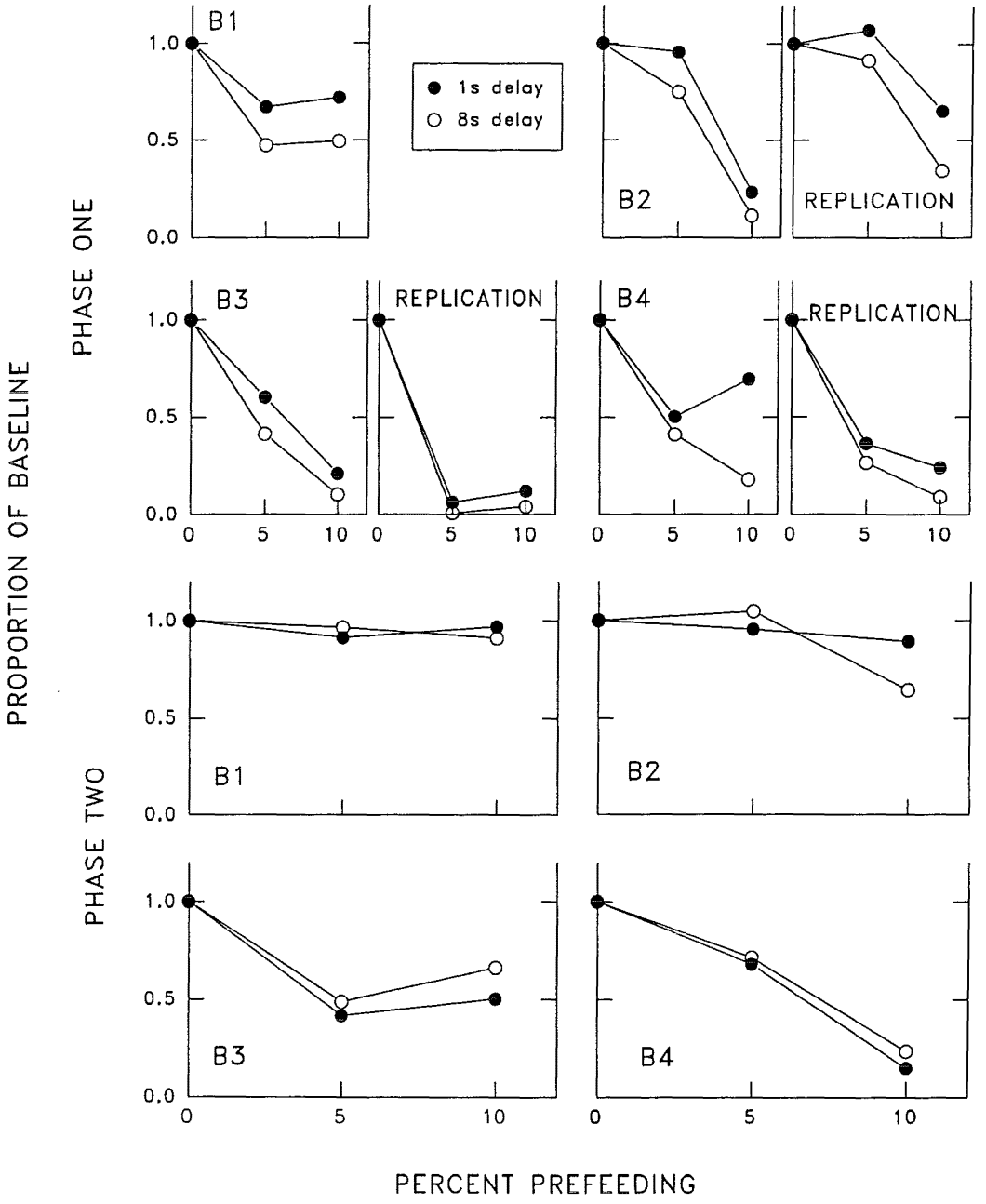

Figure 2.2. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted as a function of different amounts of prefeeding in Experiment 1. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. The bottom four panels are from the reversal condition.

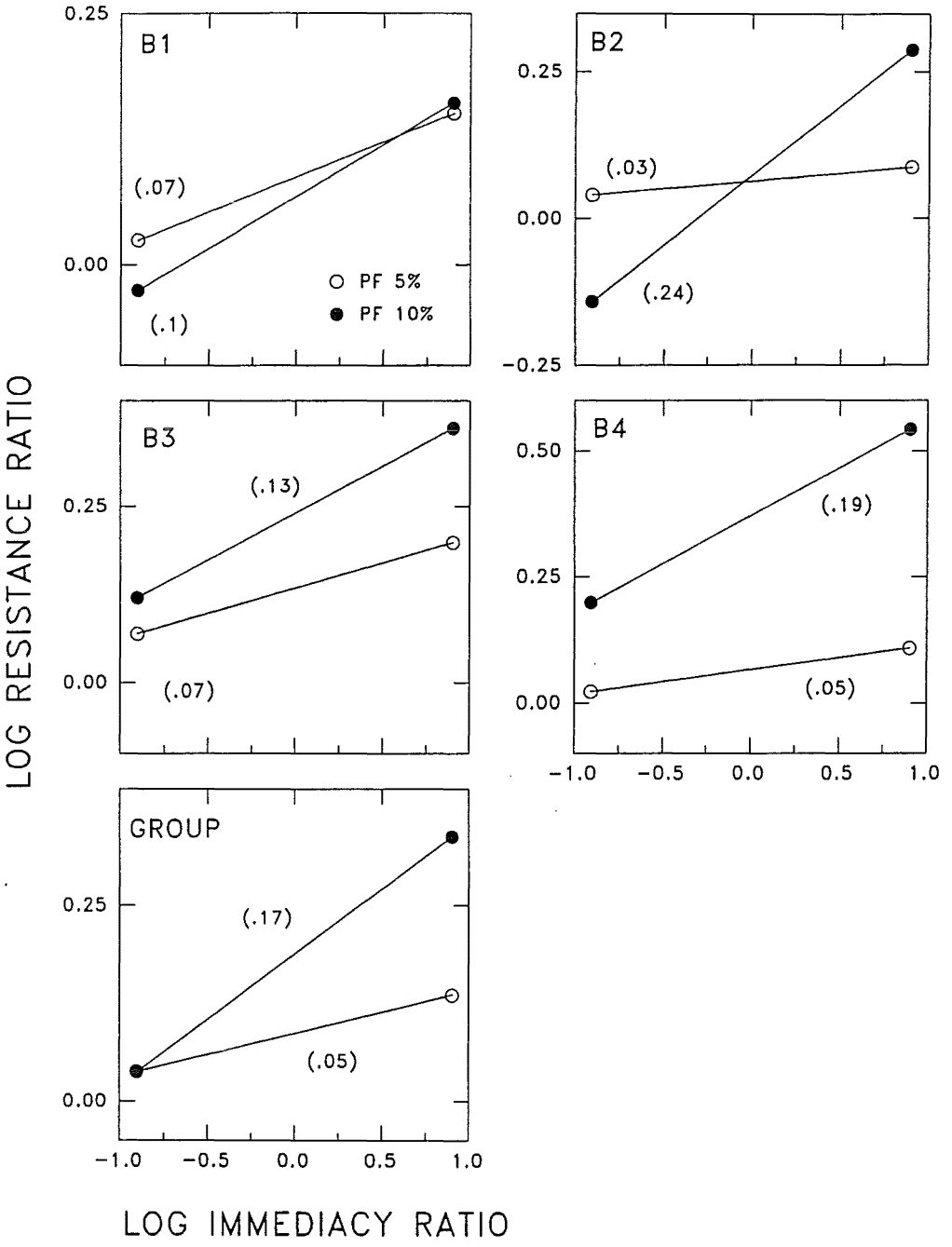

Figure 2.3. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for disruption with 5 percent (unfilled circles) and ten percent (filled circles) prefeeding in Experiment 1. The slope of each resistance function is provided in parentheses in each panel. Note that vertical and horizontal axes are unequal and that vertical axes differ between panels.

a 1 second reinforcer delay was more resistant to prefeeding than was the component with 8 seconds delay. While this effect was not always very large, it was consistent for all subjects and both strengths of disruption. In addition, the effect was reliably replicated for all three subjects (B1 did not undergo replication in Phase one as this subject was introduced to the experiment late). This is the first time that differential resistance to change effects have been demonstrated using prefeeding with delayed reinforcement, and these data are consistent with previous work using delayed reinforcement with extinction and dark-key food (Nevin, 1974).

In contrast, the outcome in Phase two was not consistent with the predictions of Behavioural Momentum Theory. As Figure 2.2 demonstrates, resistance was greatest in the component with the longest delay for B3 and B4, and no clear differences are apparent for the remaining subjects. However, prefeeding was the first disruptor to be introduced in Phase two of the experiment. It is conceivable that at this early stage in reversal, and in spite of the 51 sessions of baseline training, there may have been a residual bias in the resistance that was established during Phase one of the experiment. If resistance to change accrues as a function of exposure to reinforcement, then the results obtained for prefeeding early in Phase two might have been confounded by the extensive reinforcement history associated with the stimuli in Phase one. Thus, resistance to change effects might themselves be resistant to change.

Figure 2.3 shows log resistance ratio plotted as a function of log reinforcer immediacy ratio for disruption with prefeeding. Filled circles represent results from 10 percent prefeeding and unfilled circles represent results from 5 percent prefeeding. The slopes of the resistance functions are given in parentheses. Several points are of interest. First, the average slopes of the resistance functions for both these disruptors are much shallower than the 0.35 indicated by previous single-key resistance data (Nevin 1992a, Figure 2). This is consistent with the idea, discussed previously, that the sensitivity of relative resistance to relative reinforcement might be lower for immediacy than for other parameters of reinforcement.

More significantly though, Figure 2.3 shows that the slopes of resistance functions were consistently steeper for 10 percent than for 5 percent prefeeding. Although this effect was marginal for B1, clear slope differentials resulted for other subjects and on average, the slope for 10 percent prefeeding was 0.17 as against 0.05 for 5 percent prefeeding. This violates the

assumption that relative resistance to change should remain invariant when different magnitudes of the same disruptor are applied and is consistent with predictions made by the Quantitative Law of Effect.

Extinction.

Figure 2.4 shows rates of responding expressed as proportions of baseline, and plotted as a function of sessions of extinction in both phases of Experiment 1. Filled circles represent response rate in the component with 1 second delays and unfilled circles represent data from the component with 8 seconds delay. The results reveal a consistent pattern, with the component with a 1 second delay being most resistant to extinction. However, while this effect was robust, it was not strong for some birds. In particular, and especially in Phase one, B3 and B4 exhibited only marginal differential resistance to extinction. In general though, the results are consistent with both Behavioural Momentum Theory and the previous results obtained using extinction with delayed reinforcement (Nevin, 1974, p 399). Figure 2.5 shows resistance functions for disruption with extinction. Log resistance ratios are plotted as a function of log reinforcer immediacy ratios, and the slopes of the functions are given in parentheses. These range from 0.11 to 0.28 with an average of 0.18 and as with prefeeding, are shallower than the 0.35 obtained from studies using rate and magnitude of reinforcement.

Houselight.

Subjects had not previously responded in the presence of the houselight, so illuminating it during multiple schedule components was expected to disrupt performance. The use of the houselight as a disruptor is an interesting innovation because it is convincingly equal in its application to two differentially reinforced multiple schedule components. This procedure has a precedent in resistance to change research conducted with humans. Mace et al (1990) used a concurrent distracting stimulus to reduce responding in two multiple schedule components that involved a sorting task and the procedure employed here can be viewed in a similar way.

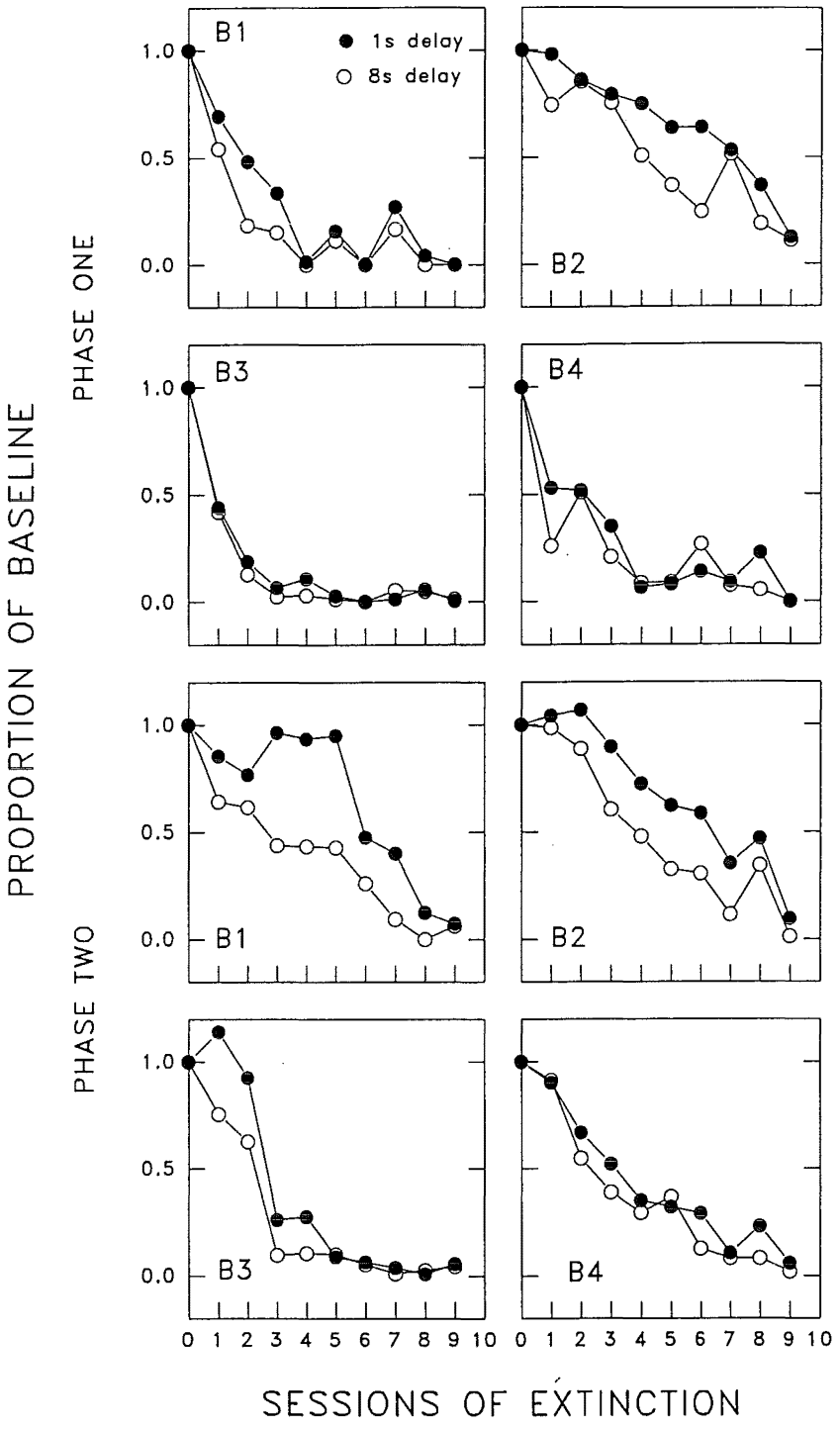

Figure 2.4. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted as a function of extinction in Experiment 1. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. The bottom four panels are from the reversal condition.

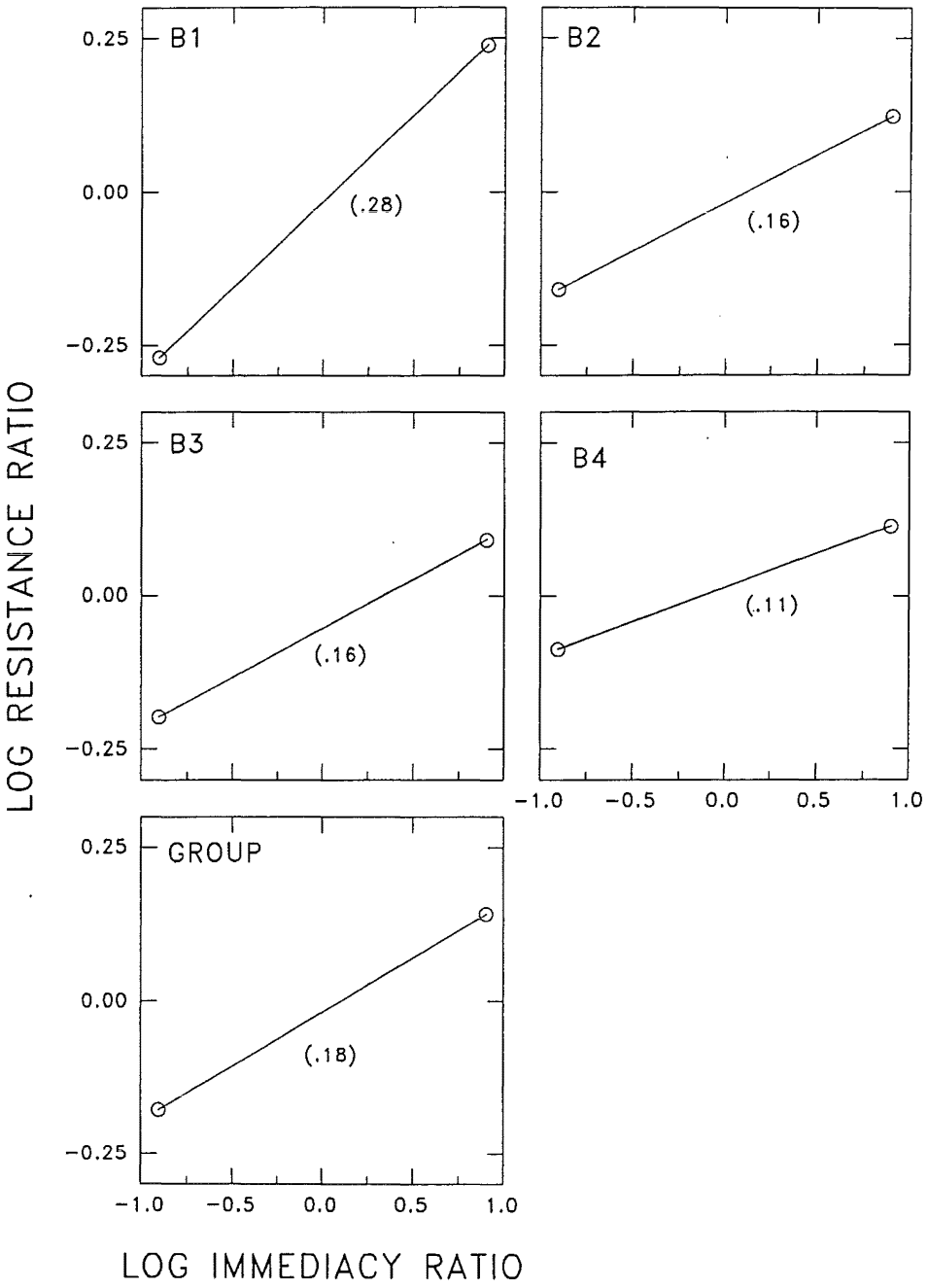

Figure 2.5. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for disruption with extinction in Experiment 1. The slope of each resistance function is provided in parentheses in each panel. Note that vertical and horizontal axes are unequal.

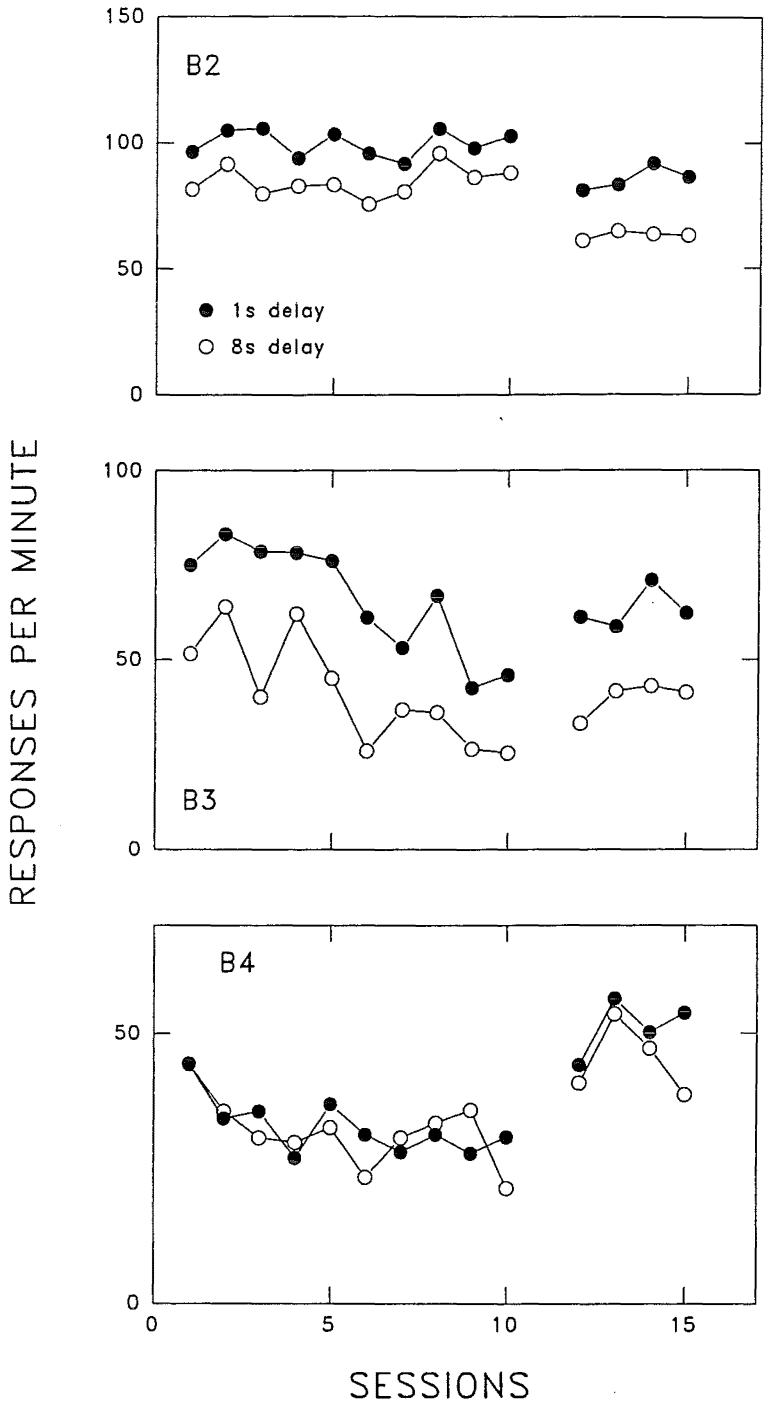

Figure 2.6. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted over ten days of baseline training and four days of disruption with the houselight. Response rates for both components are expressed as responses per minute.

In Figure 2.6, response rate in both components is plotted as a function of sessions of disruption, with the component with 1 second delay being represented by filled circles. This figure shows that the houselight produced ambivalent results, with only one bird convincingly reducing its rate of responding in the presence of the houselight. In contrast, one bird accelerated its rate of responding and despite 30 sessions of baseline training, the baseline for B3 was too variable to evaluate the effect of disruption. The attempt to use the houselight as a concurrent distracting stimulus failed because it did not systematically reduce the rate of responding across subjects. Accordingly, houselight disruption was not attempted in Phase two.

Dark-key food.

Figures 2.7 and 2.8 show response rates during disruption with dark-key food, expressed as proportion of baseline, and plotted across sessions. The component with 1 second delay is represented by the filled circles, while data from the component with 8 seconds delay are represented by unfilled circles. In Phase one (Figure 2.7), B1 and B2 demonstrate a clear differential resistance effect that is consistent with Behavioural Momentum Theory and with previous results obtained with delayed reinforcement and dark-key food (Nevin, 1974, p 398). That is, the component maintained by most immediate reinforcement was most resistant to the effect of disruption. The same pattern was evident for B4, but the effect was marginal. In contrast, the results obtained from B3 showed a pattern completely opposite to that predicted by Behavioural Momentum Theory, with the performance maintained on the longest delay being most resistant to disruption with dark-key food. In Phase two (Figure 2.8), a similar pattern of results was obtained for all subjects.

Figure 2.9 shows log resistance ratio plotted as a function of log reinforcer immediacy for disruption with dark-key food. Filled circles represent results from disruption with VT 30-s dark-key food and unfilled circles represent data obtained with VT 60-s disruption. The results from B1 and B2, as well as the group data, are consistent with the pattern of results obtained with prefeeding. The slopes of resistance functions are much lower than 0.35 and in addition, the disruptor with the largest magnitude produced the steepest resistance function. The same is

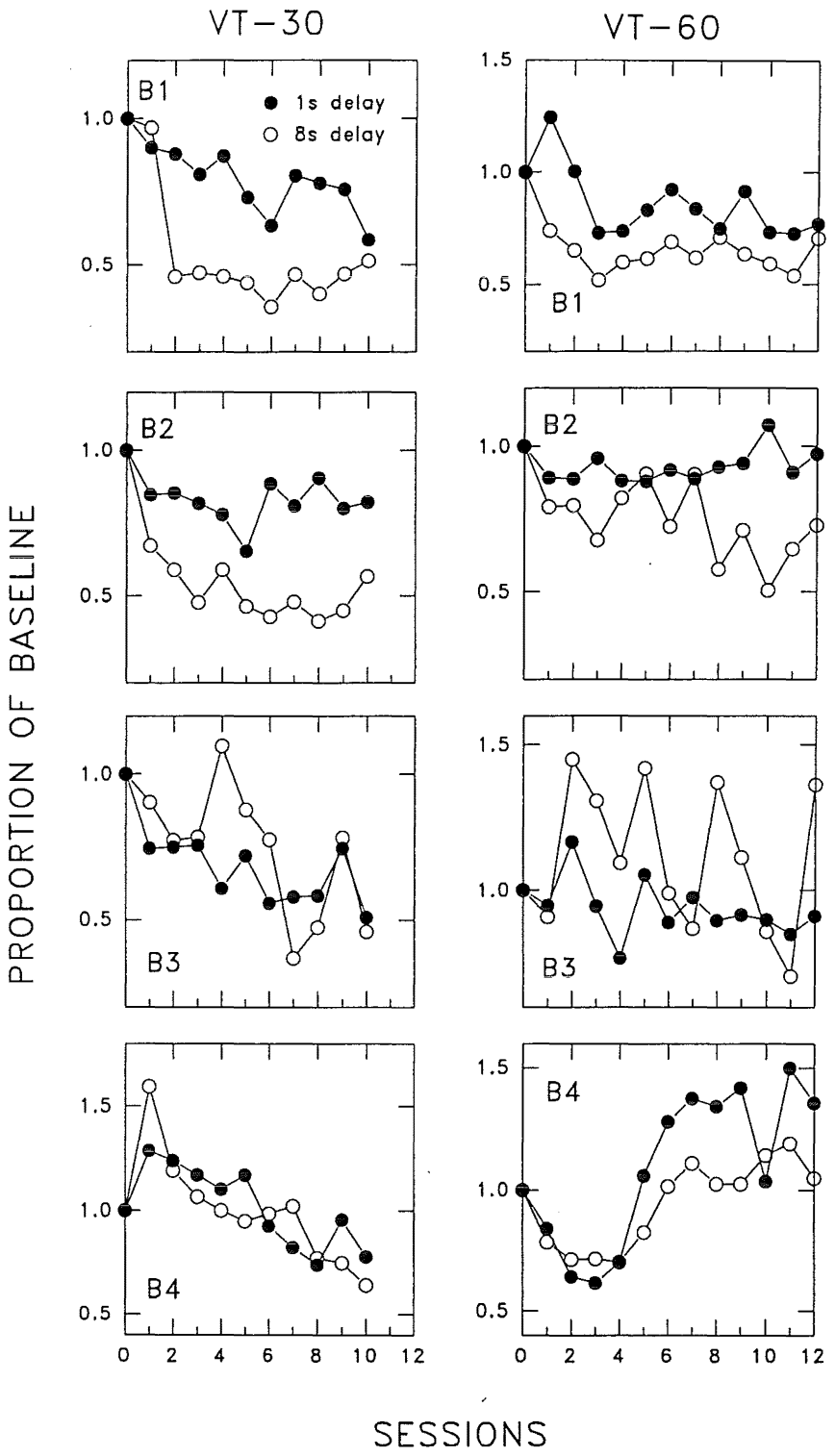

Figure 2.7. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted across sessions of disruption with two magnitudes of dark-key food in Phase 1 of Experiment 1. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. Note that vertical axes differ between panels.

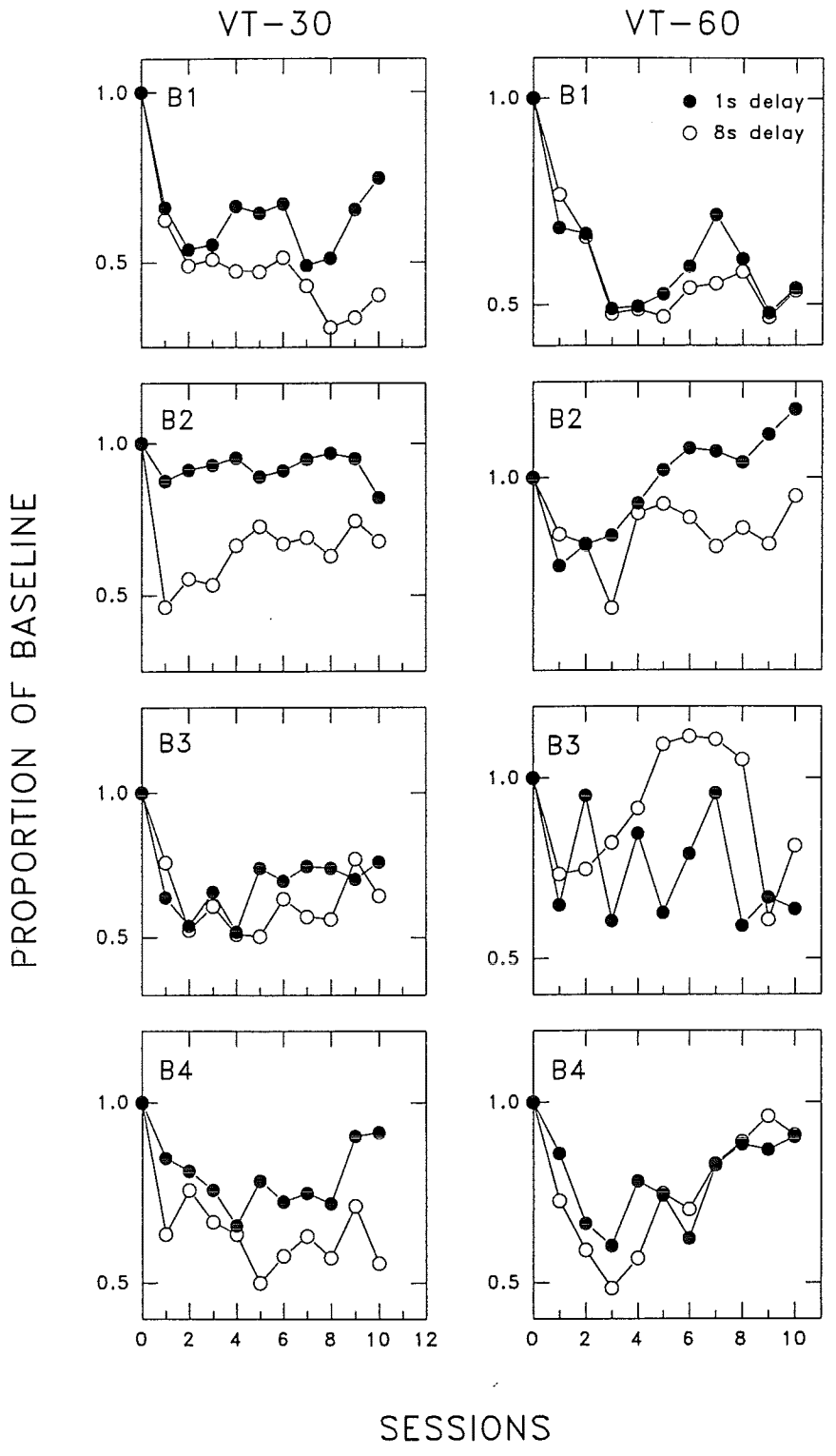

Figure 2.8. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted across sessions of disruption with two magnitudes of dark-key food in Phase 2 (reversal) of Experiment 1. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. Note that vertical axes differ between panels.

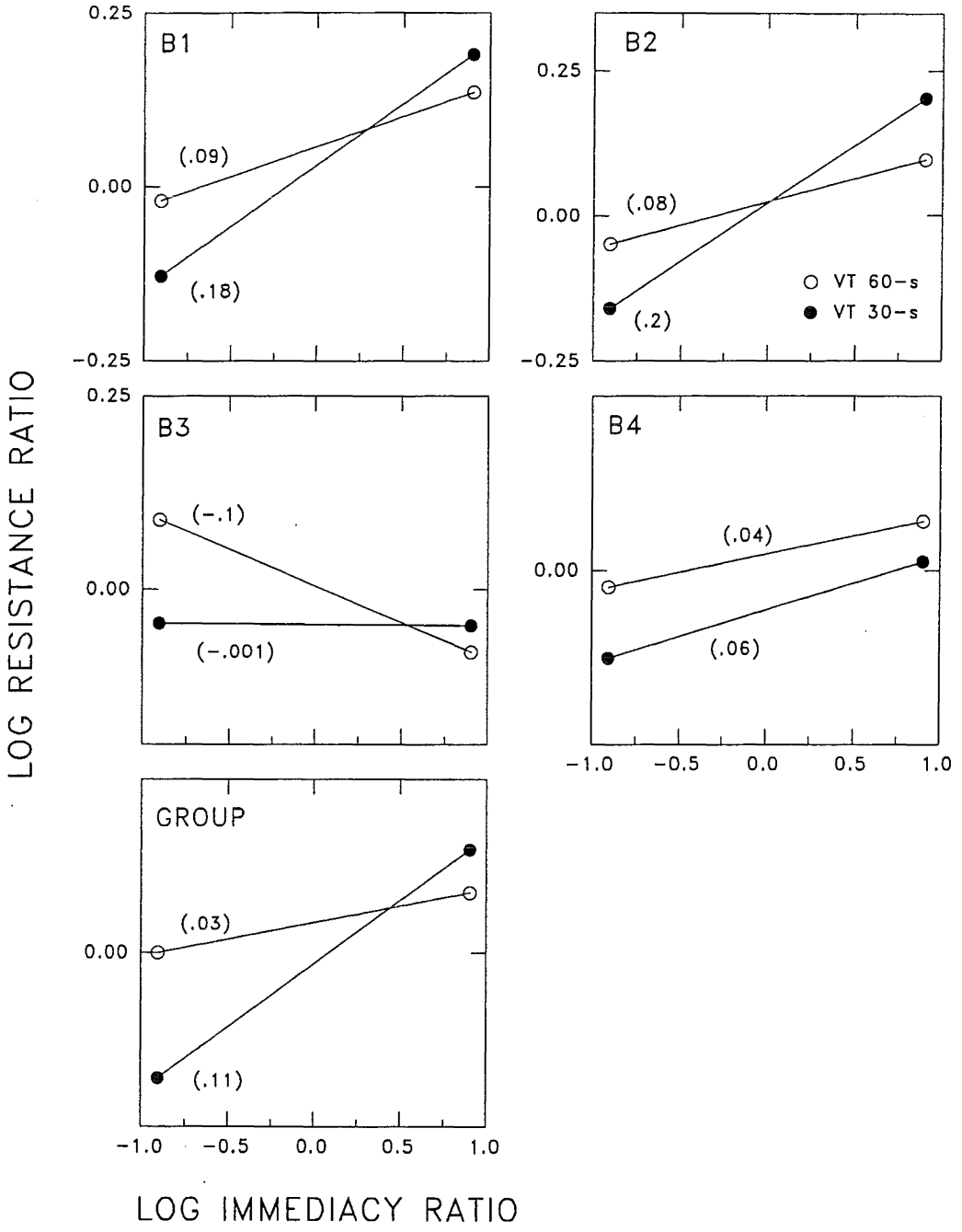

Figure 2.9. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for disruption with VT 60-s (unfilled circles) and VT 30-s (filled circles) dark-key food in Experiment 1. The slope of each resistance function is provided in parentheses in each panel. Note that vertical and horizontal axes are unequal and that vertical axes differ between panels.

true for B4, but the effect is very small. B3 did not conform to this pattern and the lack of a consistent result across all subjects when dark-key food was used as a disruptor could be the result of a peculiarity of using dark-key food to disrupt responding maintained by delayed reinforcement. Because delayed reinforcement and presentations of dark-key food are both predicted by the absence of a lit key, there is a degree of stimulus similarity between these experimental events. This could complicate the procedure and Experiment 2 was designed to address this possibility.

Conclusion.

Generally, Experiment 1 successfully replicated previous resistance research with delayed reinforcement (Nevin, 1974). In addition to using extinction and dark-key food, this experiment extended previous findings by using prefeeding and a concurrent distracting stimulus to measure relative resistance. Despite some exceptions, and as predicted by Behavioural Momentum Theory, the component with more immediate reinforcement was generally most resistant to disruption.

This experiment also allows comparison of data from delayed reinforcement with Nevin's (1992a, Figure 2) summary of existing single-key multiple schedule resistance studies. Previous work with delayed reinforcement (Nevin, 1974) is not shown in this summary because it used two keys, but suggested that the sensitivity of relative resistance to relative reinforcement might be lower for immediacy than for other parameters of reinforcement. Experiment 1 confirmed that when analysed using averaged proportions of baseline, delayed reinforcement produced resistance functions with slopes that were much lower than the 0.35 obtained across studies that used rate and magnitude of reinforcement.

A deficiency of Nevin's summary of single-key data is that because it presents group results obtained across different experiments that have used different subjects, it may conceal systematic variation in mass ratios obtained using different types or magnitudes of disruption. The within-subjects nature of Experiment 1 means that this issue can be addressed. While results from this experiment do not support the idea that different types of disruptor produce

mass ratio variation, they are consistent with the expectation, based on the Quantitative Law of Effect, that different magnitudes of disruption should do so.

As discussed previously, there are several reasons to suppose that mass ratios might vary when different types of disruptor are used. First, because extinction might entail more force for a rich component than a lean one, this procedure could be expected to produce shallower resistance functions than other disruptors. However, results obtained using extinction in Experiment 1 show that overall, this disruptor produced a steeper resistance function than other procedures.

A second reason to expect that mass ratios might vary when different types of disruptor are used is that either extinction or dark-key food should comprise more force for one component than another. If force is defined in absolute terms, extinction involves reducing reinforcement more in one component than in another, and should produce small mass ratios as a result. As this experiment shows, this did not occur. Alternatively, if force is construed proportionally, extinction comprises the same force in each component, but dark-key food represents more force for a leaner component than a rich one. This also predicts larger mass ratios for dark-key food than for extinction. However, on average, extinction produced a steeper resistance function than both magnitudes of dark-key food.

It follows that results from Experiment 1 do not support the idea, raised in the introduction, that different types of disruptor might produce systematic variation in mass ratios. However, this experiment did find that different magnitudes of disruption produced systematic variation in mass ratios and resistance functions. In most cases, larger disruptors produced steeper resistance functions than smaller ones. This is consistent with predictions based on the Quantitative Law of Effect, and inconsistent with Behavioural Momentum Theory.

2.2 EXPERIMENT 2.

It is conceivable that when dark-key food is used to assess resistance in components maintained by delayed reinforcement, this procedure could increase resistance in the component maintained by less immediate reinforcement. The introduction of dark-key food results in more reinforcement occurring in the presence of black-out, and in terms of Gibbon's stimulus-reinforcer contingency (Nevin, 1992b, p 133), this may make responses in the component with long reinforcement delays more resistant to change by increasing the amount of reinforcement in the presence those stimulus conditions. This might account for the countervailing results yielded by B3 and the marginal results obtained from B4 when dark-key food was used in Experiment 1.

If the ambivalent results obtained using dark-key food in Experiment 1 are due to the difficulty described here, a procedure where these experimental states occur in the presence of distinctive stimuli should yield less equivocal results. Experiment 2 sought to achieve this by illuminating the houselight during the inter-component interval. In Experiment 2, response-independent reinforcers presented during the intercomponent interval should not 'add mass' to responding in the component with long reinforcer delays, because these states should be more discriminable.

METHOD.

Subjects and Apparatus.

Time constraints prohibited the use of the subjects used in Experiment 1. Four additional pigeons were used, with similar histories and identical home cage arrangements to the birds in the first experiment. Apparatus was identical to that used in Experiment 1.

Procedure.

This experiment employed a similar procedure to that used in Experiment 1, the only major departure being the illumination of the houselight during intercomponent intervals. Experimental sessions were conducted daily and consisted of twenty-eight multiple schedule components. Red and green components were presented equally often and in random order, and each component was preceded by a 30-s intercomponent interval during which the houselight was illuminated. In Phase one of the experiment red-key responses obtained reinforcers with 1-s delays and green-key responses obtained reinforcers with 8-s delays. This was reversed in Phase two for Subjects C1 and C2 and the resistance tests repeated. Due to a programming error, C3 and C4 did not have their reinforcement delays reversed during Phase two, and these birds replicated Phase one. This error was not detected until it was too late to rectify it.

Resistance was tested by presenting response-independent food reinforcers during the inter-component interval when the houselight was illuminated. Three second presentations of food were arranged according to either a VT 30-s or a VT 120-s schedule. All subjects underwent the same order of resistance testing, given in Table 3.

Table 3.

Order of conditions in Experiment 2 showing the number of sessions in each condition. Phase 2 comprises a reversal of the reinforcer delays in Phase 1 for C1 and C2, and replication of Phase 1 for C3 and C4.

Condition	Description	Number of sessions
Phase 1		
1	Baseline	40
2	VT 120-s	6
3	Baseline	21
4	VT 30-s	10
Phase 2		
5	Baseline	51
6	VT 120-s	6
7	Baseline	30
8	VT 30-s	10

RESULTS AND DISCUSSION.

Figure 2.10 shows log response ratio during baseline training, plotted as a function of log reinforcer immediacy ratio. Data are connected by least-squares regression functions and the slopes of these are given in parentheses, indicating the sensitivity of log response ratios to log immediacy ratios. The sensitivity of response ratios to immediacy ratios could be assessed only for C1 and C2, but displayed a similar variability to that seen in the first experiment. The group data include response ratios for all birds and suggest that in this experiment relative responding was, overall, more sensitive to relative delay than in Experiment 1. A subtle difference between the experiments was the way in which reinforcement delays were introduced. In Experiment 1, delays were progressively faded into the procedure over 45 sessions, while in the second experiment they were introduced more rapidly over 20 sessions. Mazur and Logue (1978) have shown that sensitivity to delay is reduced when delays are gradually faded in, and this may explain the difference in the sensitivity of response ratios to delay ratios that emerged between Experiments 1 and 2.

Figures 2.11 and 2.12 show responding during two magnitudes of disruption, expressed as proportion of baseline for each component, and plotted over successive sessions. Filled and unfilled circles represent components with 1 second and 8 seconds reinforcer delays respectively. Disruption with VT 120-s intercomponent reinforcement had minimal effect in terms of differentially reducing responding. The effect was strongest for C4 in Phase one and possibly C1 in Phase two of the experiment. In spite of the weakness of the effect, it was generally consistent with the prediction that the component with the shortest delay should be most resistant to disruption. C2 and C3 in Phase one, and C2 in Phase two did not conform to this pattern, for the former birds this is because free-food failed to have much effect in reducing absolute response rates.

Figures 2.11 and 2.12 indicate that VT 30-s intercomponent reinforcement was more successful in reducing absolute response rates than was disruption with VT 120-s reinforcement. However, although mass differentials were again consistent with the predictions

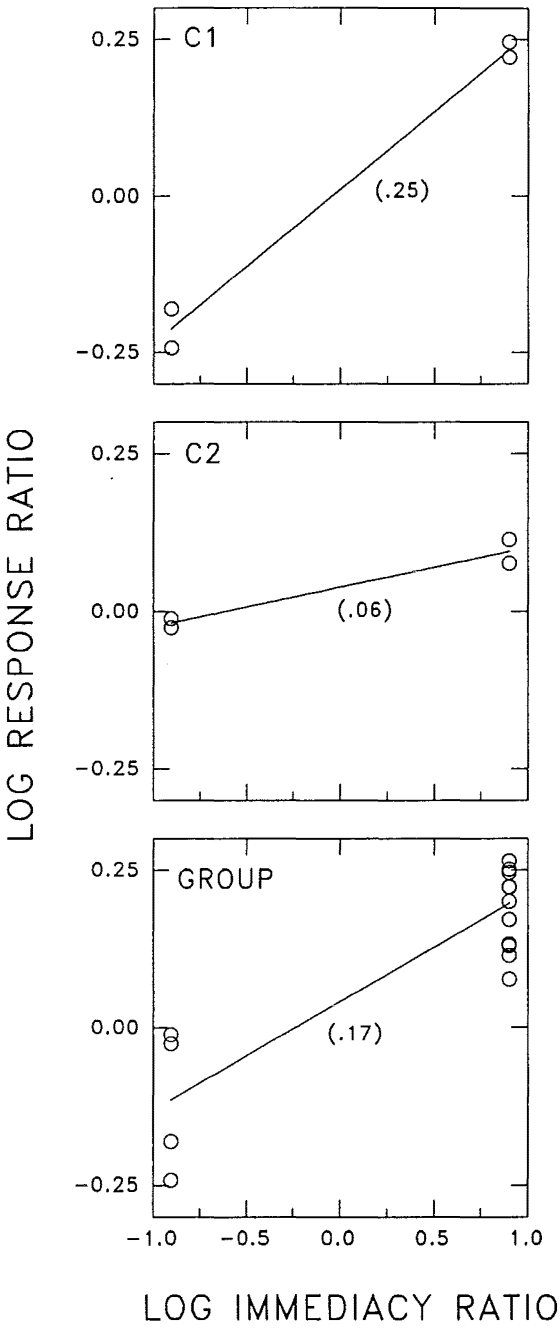

Figure 2.10. Log response ratios in baseline plotted as a function of log reinforcer immediacy ratios in Experiment 2. The slopes of least-squares regression lines are given in parentheses in each panel. Note that vertical and horizontal axes are unequal and that group data includes results from all subjects.

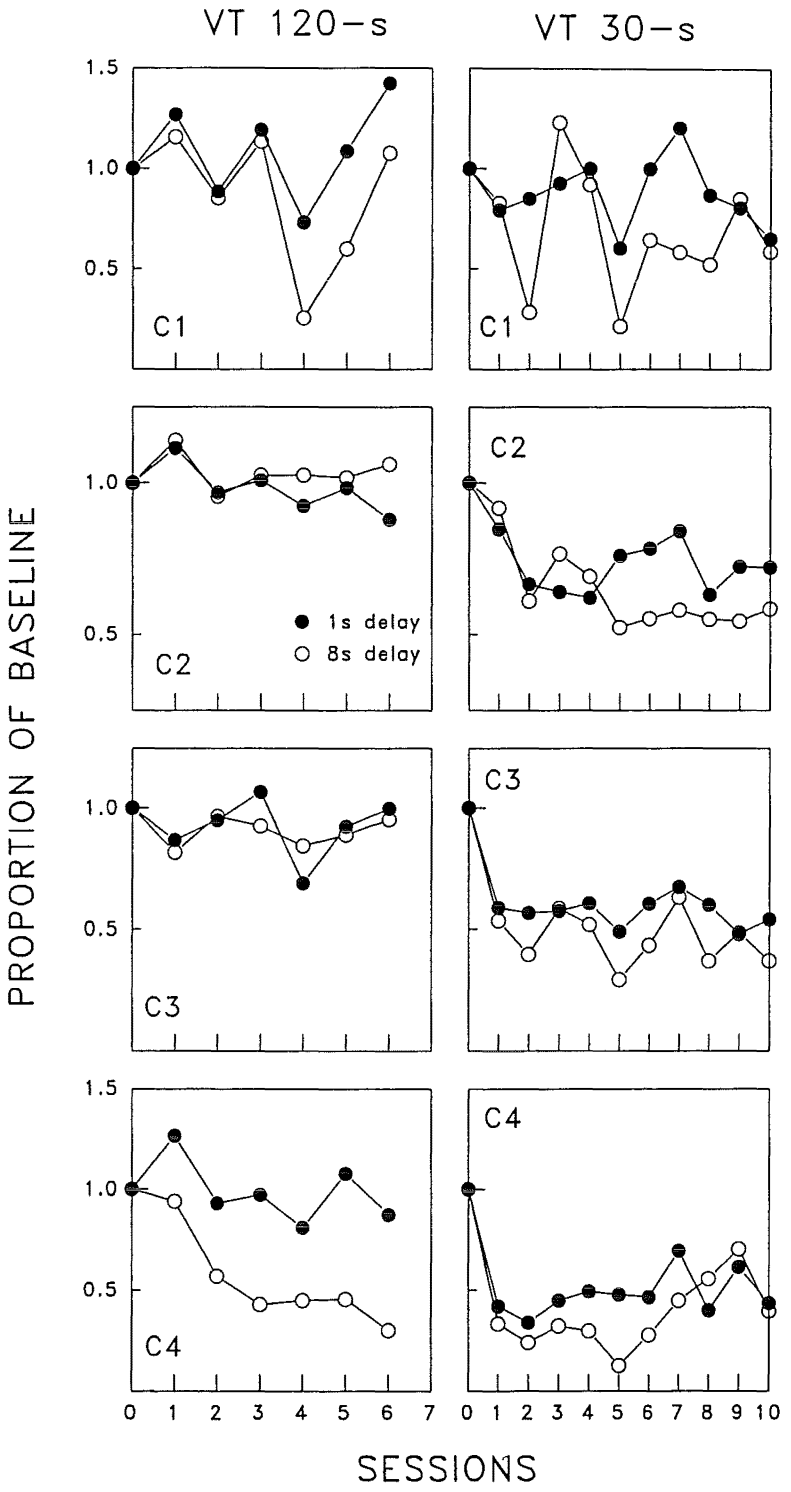

Figure 2.11. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted across sessions of disruption with two magnitudes of response-independent food in Phase 1 of Experiment 2. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. Note that vertical axes differ between panels.

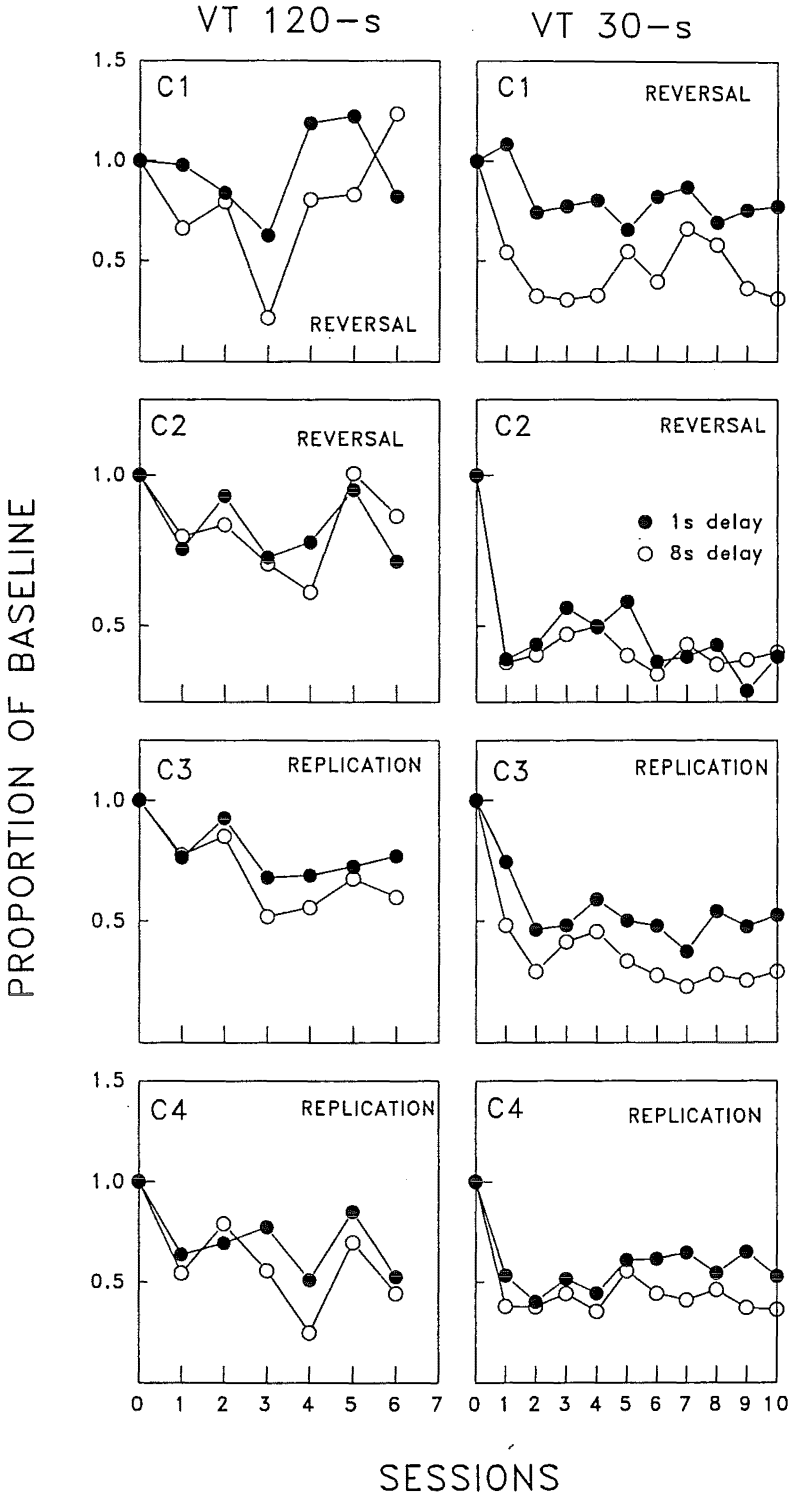

Figure 2.12. Response rate in short-delay (filled circles) and long-delay (unfilled circles) components, plotted across sessions of disruption with two magnitudes of response-independent food in Phase 2 of Experiment 2. For each component, response rate is expressed as a proportion of the response rate observed during baseline training. Note that C3 and C4 did not undergo reversal, and that vertical axes differ between panels.

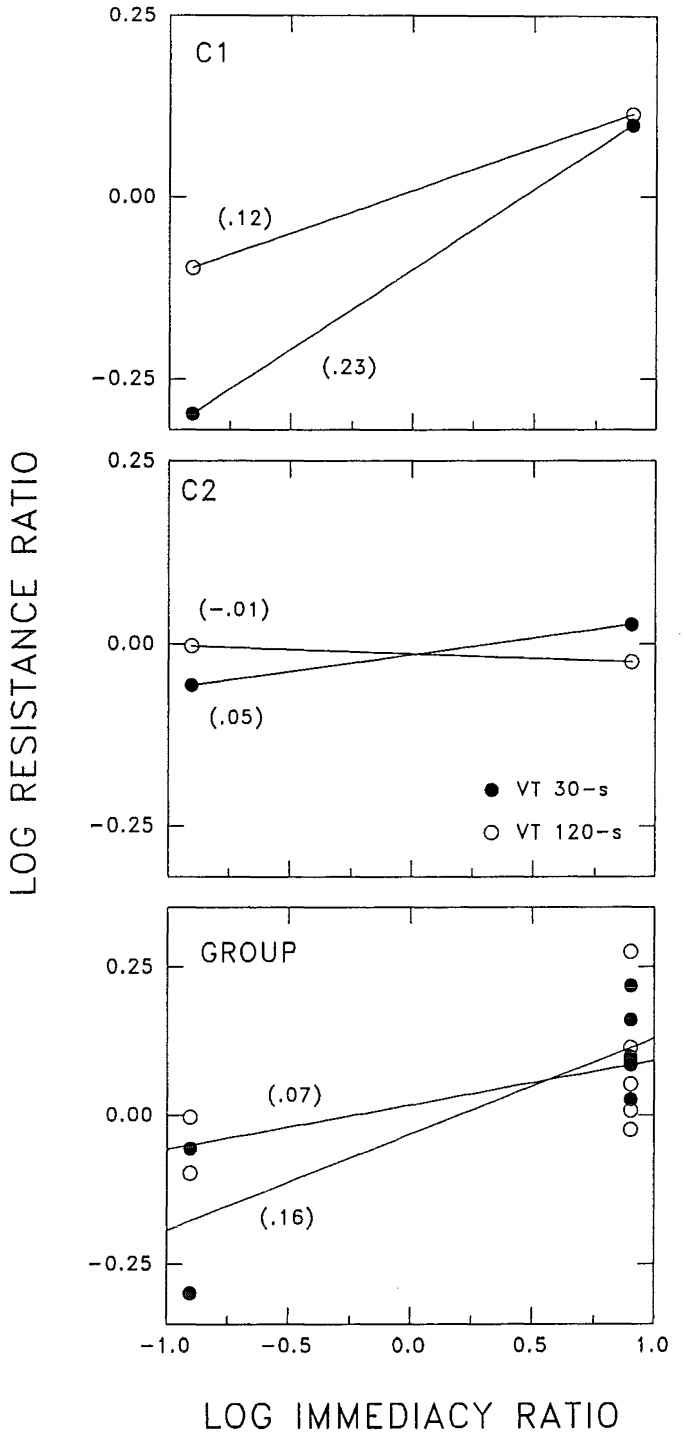

Figure 2.13. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for disruption with VT 120-s (unfilled circles) and VT 30-s (filled circles) response-independent food in Experiment 2. The slope of each resistance function is provided in parentheses in each panel. Note that vertical and horizontal axes are unequal and that vertical axes differ between panels. Group data includes results from all subjects.

of momentum theory, the mass differential effect was not strong. Table 4 lists the mass ratios obtained in all conditions of the experiment.

Table 4.

Mass ratios derived using the ratio of average proportion of baseline for each component in Experiment 2 and presented in logarithmic form.

Phase 1	C1	C2	C3	C4
VT 120-s	0.114	-0.025	0.008	0.275
VT 30-s	0.099	0.026	0.094	0.218
Phase 2	[Reversal]		[Replication]	
VT 120-s	-0.097	-0.003	0.059	0.086
VT 30-s	-0.298	-0.057	0.160	0.088

In Figure 2.13, log resistance ratios are plotted as a function of log reinforcer immediacy ratios. Filled circles represent disruption with VT 30-s intercomponent reinforcement and unfilled circles represent VT 120-s disruption. The slopes of the resistance functions are given in parentheses, and these are similar to those obtained using dark-key food in Experiment 1. C1 reveals a pattern identical to that obtained from B1 and B2, with the disruptor possessing larger magnitude resulting in a resistance function with a steeper slope. C2 produced similar functions, although the effect is much weaker and may reflect a result where the weaker disruptor (VT 120-s) failed to influence responding while the stronger disruptor (VT 30-s) did. The group results are consistent with the finding from prefeeding and dark-key food in Experiment 1, that disruptors with a larger magnitude result in steeper resistance functions. Similarly, the slopes of resistance functions were also, on average, much lower than 0.35.

It is unfortunate that C3 and C4 did not undergo reversal as intended. This meant that resistance functions could only be obtained for two birds, making it difficult to assess the success of the modified procedure. However, an analysis which does support the success of the procedure adopted in Experiment 2 is presented in Figure 2.14.

Figure 2.14 shows the relationship between log response ratio and log resistance ratio for disruption with VT reinforcement during the intercomponent intervals in both Experiment 1 and Experiment 2. In this figure, log resistance ratios are displayed as a function of log response ratios in the preceding (baseline) condition, and filled circles represent results obtained with VT 30-second disruption in both experiments. This analysis is suggested by the

observation that for C2, both response ratios and resistance ratios were rather insensitive to relative reinforcement delay. If both of these measures share dependence upon sensitivity to delayed reinforcement, there should be a positive relationship between relative response rate and relative resistance to change.

Figure 2.14 explores this possibility, and two things are evident. First, there is a much better correlation between resistance and response ratios for the data in Experiment 2. This indicates that the procedure in this experiment resulted in "cleaner" data, and suggests that the poor correlation evident in Experiment 1 is the result of the confounding influence that the modified procedure was designed to circumvent. Second, the results from Experiment 2 in this figure are consistent with the finding that disruptors with larger magnitudes result in steeper resistance slopes. Even though this analysis measures resistance slopes as a function of response ratio, the relationship between disruptor magnitude and resistance slope is preserved. In terms of this analysis then, Experiment 2 can be construed as a success and importantly, the data are consistent with those obtained from prefeeding and dark-key food in Experiment 1.

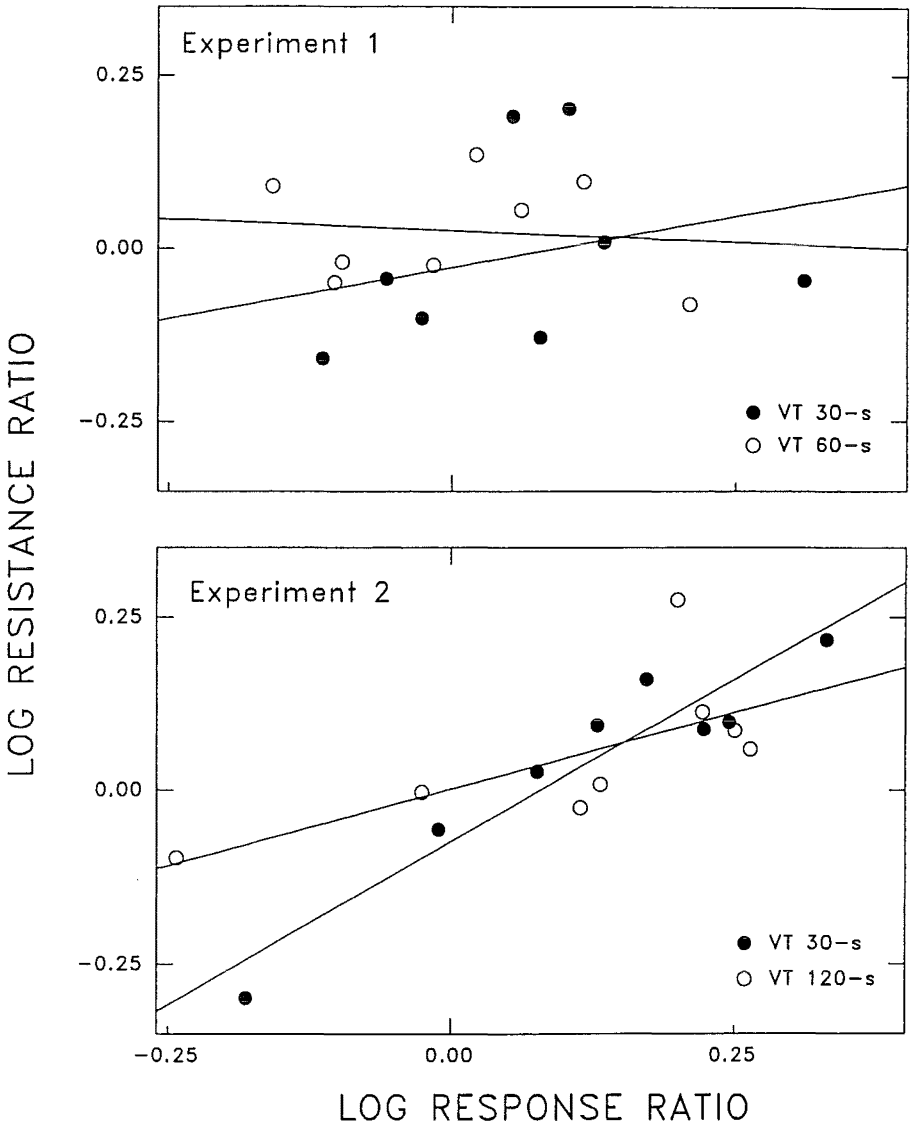

Figure 2.14. Log resistance ratios plotted as a function of log response ratios for disruption with different magnitudes of response-independent food in Experiments 1 and 2. Note that magnitudes of response-independent food differ between panels.

3.1 SUMMARY OF RESULTS.

The present study comprised a systematic replication and extension of previous behavioural momentum research (Nevin, 1974, 1992a, 1992b; Nevin et al, 1983), and examined the disruptive effects of different types and magnitudes of disruption in a within-subjects single-key multiple schedule procedure where components differed in immediacy of reinforcement. Results from the present study are of interest because they provide the first single-key multiple schedule resistance data where components differed in terms of reinforcement delay, and because a comprehensive within-subjects procedure provides a good test of the assumption that mass ratios will remain invariant when different types and magnitudes of disruption are used to measure relative resistance.

Figure 3.1 summarises the results of Experiments 1 and 2 in terms of the slopes of resistance functions. Log resistance ratios are plotted as a function of log reinforcer immediacy ratios, showing the results from each disruptor for individual subjects. To make comparison of the slopes of resistance functions easier, functions have been translated vertically so that y-intercepts are identical. Figure 3.2 A shows group data from Experiment 1, and the slopes of the resistance functions in this figure are listed in Table 5.

Table 5.

Slopes of resistance functions obtained in Experiment 1 and presented in Figure 3.2 A. Mass ratios have been calculated using the APOB method.

Extinction	0.177
Prefeeding 10%	0.167
Dark-key food VT 30-s	0.109
Prefeeding 5%	0.054
Dark-key food VT 60-s	0.029

Several things are evident from these results. First, consistent with expectations based on Nevin's 1974 results, the resistance functions obtained in the present study are much shallower than 0.35. Second, results from the present study are inconsistent with the idea, discussed previously, that extinction should produce smaller mass ratios than other disruptors. Finally, group data, as well as those from individual subjects, show a systematic pattern of variation in

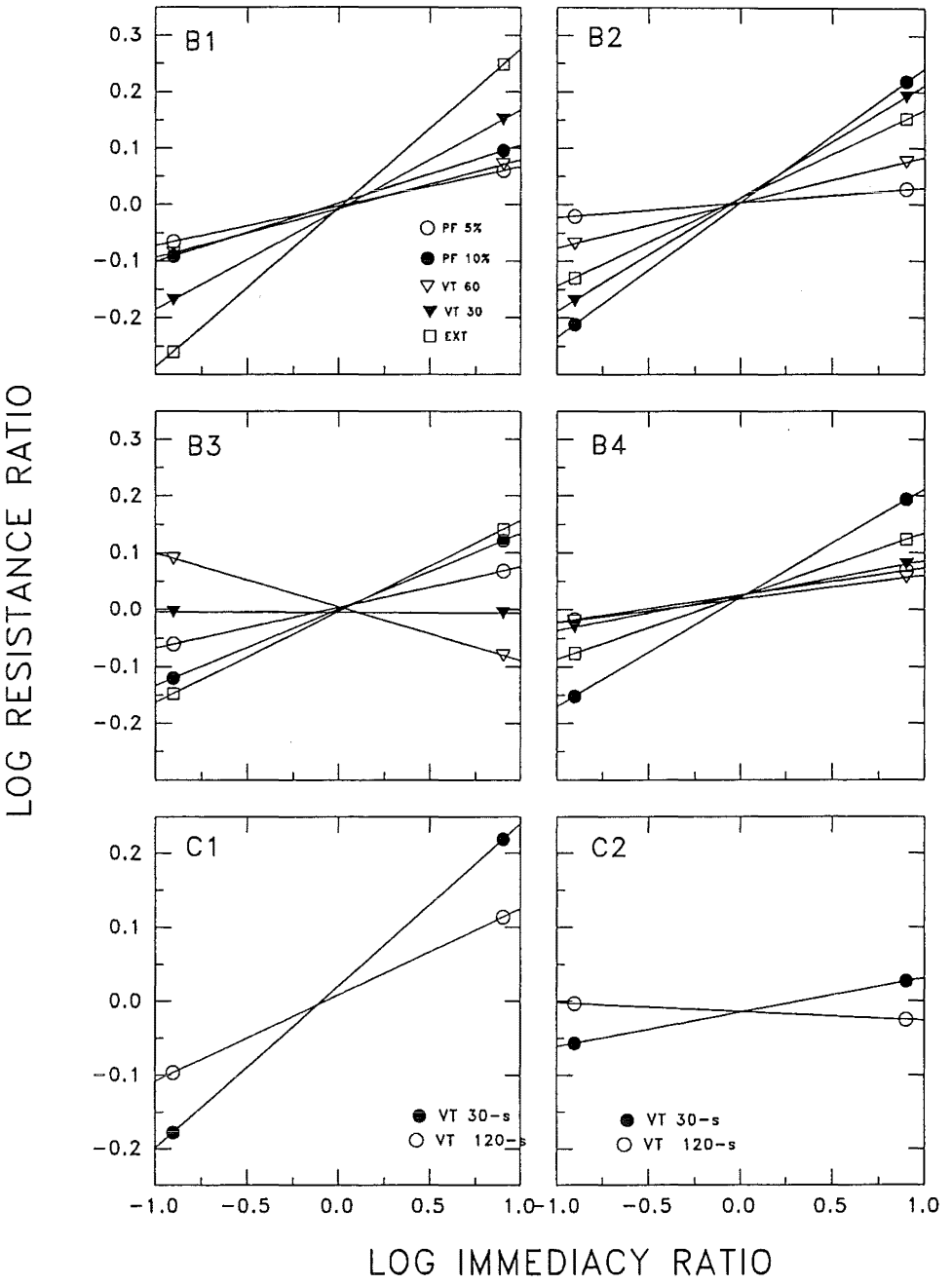

Figure 3.1. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for different types and magnitudes of disruption in Experiments 1 and 2. Note that resistance functions have been arranged so that they share a common intercept, however, the slopes of functions have not been altered. In addition, vertical and horizontal axes are unequal and vertical axes differ between panels.

the slopes of resistance functions, with larger magnitudes of disruption almost invariably resulting in steeper resistance functions. For example, 10 percent prefeeding (filled circles) produced steeper functions than 5 percent prefeeding (unfilled circles), and the same pattern was generally evident for disruption with two magnitudes of dark-key food. Similarly, extinction (represented by unfilled squares) consistently resulted in steeper slopes than both 5% prefeeding and VT 60-s dark-key food, and this is consistent with the idea that extinction represents a larger force than either of these disruptions. Systematic variation of this kind is inconsistent with analysis in terms of a single linear function such as the quantitative model for resistance to change but is consistent with predictions made by the Quantitative Law of Effect.

3.2 DELAYED REINFORCEMENT.

In the present study, the sensitivity of relative resistance to relative immediacy was considerably lower than the 0.35 predicted by Nevin's (1992a, Figure 2) summary of single-key multiple schedule resistance studies using rate and magnitude of reinforcement. However, this result is consistent with Nevin's 1974 study that used delayed reinforcement in a two-key resistance study. In the present study, the slopes of resistance functions in Experiment 1 averaged 0.11 and the steepest slope for any disruptor was 0.18. In Experiment 2, which was designed to make experimental conditions associated with dark-key food clearly discriminable, the average slope was 0.12. Although these experiments were consistent in finding that delayed reinforcement produced much shallower resistance functions than those obtained in studies using reinforcer rate and magnitude, it will become clear that this is at least partly a result of using APOBs to calculate mass ratios.

The present study also provided an opportunity to examine the sensitivity of response ratios to reinforcer immediacy ratios (Generalised Matching Law sensitivity) in multiple schedules. A recent review of multiple schedule research (McSweeney, Farmer, Dougan and Whipple, 1986) did not include data on delayed reinforcement, but found a mean GML sensitivity of 0.45 across studies using other parameters of reinforcement. Compared with this value, the average sensitivity of 0.1 in Experiment 1 is very low. This could have resulted from the fading

procedure that was used to introduce delayed reinforcement (Mazur and Logue, 1978). However, delays were introduced more rapidly in Experiment 2 and although the average GML sensitivity then increased to 0.17, this is still much lower than 0.45.

3.3 TYPE AND MAGNITUDE OF FORCE.

Behavioural Momentum Theory requires that mass ratios and the slopes of resistance functions remain invariant when relative resistance is measured using different types or magnitudes of disruption. This is inherent in both the quantitative model for resistance to change (Nevin, 1992a) and the logic underlying the experimental paradigm used in momentum research (Nevin et al, 1983; Nevin 1992a). Existing work, summarised by Nevin (1992a, Figure 2), suggests that the slope of the resistance function relating relative resistance to relative reinforcement is about 0.35. With the exception of one set of data from extinction, there are no obvious deviations from this value when different rates and magnitudes of reinforcement, or different types of disruptor are used.

However, as discussed previously, there are a number of reasons to expect that mass ratios might vary as a function of type and magnitude of disruption. Thus, an important question in the present study was whether the mass ratio invariance assumption would be upheld. Figure 3.1 shows that consistent with predictions made by the Quantitative Law of Effect, mass ratios increased as a function of increased magnitudes of disruption.

In contrast, the idea that mass ratios might vary as a function of disruptor type was not supported. One reason to expect variation between different types of disruptor was that extinction might apply more force to a rich component than a lean one, either because the generalisation decrement is larger for a rich component or because extinction removes a larger value of reinforcement from a rich component than a lean one. In the present study, where components differed in terms of reinforcer delay rather than rate, the generalisation decrement should be the same for each component. Nevertheless, extinction terminates a higher value of reinforcement in a component with a 1 second reinforcer delay than in a component with an 8 second reinforcer delay. This implies that the rich component might be subjected to a larger

force than the lean one and suggests that extinction might produce smaller mass ratios and shallower resistance functions than other disruptors. However, Figures 3.1 and 3.2 show that overall, extinction produced the steepest resistance functions. This result is not consistent with the expectation that different types of disruptor should produce systematic variation in mass ratios.

Another reason to expect systematic variation in mass ratios came from the idea that either extinction or dark-key food should comprise different forces for different components, depending on whether forces are construed in absolute or proportional terms. Forces can be construed proportionally, in which case extinction represents the same force in each component while dark-key food comprises more force for a lean component than a rich one. Alternatively, if forces are construed absolutely, dark-key food is equal in each component and extinction constitutes a larger force for a rich component than a lean one. Both of these possibilities predict steeper resistance functions for dark-key food than for extinction, and again, the finding that extinction obtained steeper resistance functions than dark-key food fails to support the idea that different types of disruptor should produce systematically variable mass ratios.

Analytical considerations.

The relationship between magnitude of disruption and the slopes of resistance functions that was found in the present study is difficult for a theory which requires that mass ratios remain invariant when different types and magnitudes of disruptor are employed. However, because the present study used a different method of calculating mass ratios to that employed in recent work, it might be argued that this result is a computational artifact.

In recent resistance studies (Nevin, 1992a; 1992b), relative resistance is measured in terms of the declining slopes of response rate functions when increasing magnitudes of disruption are applied. To avoid dependence on baseline response levels, log transformed data are used, and resistance ratios are defined as the inverse of the ratio of slopes (because steeper slopes reflect less resistance to disruption). Thus, log transformed data from baseline and the first few sessions of disruption in each component are plotted as a function of sessions. Regression lines

are fitted to data obtained from each component during disruption, the slopes of which characterise the rate of change in log response rate under disruption. The inverse ratio of the slopes obtained in this way provides the measure of relative mass.

Figure 3.2 B shows log resistance ratios plotted as a function of log immediacy ratios, using the ratio of slopes method, for disruption with prefeeding, dark-key food and extinction in Experiment 1. As in recent publications relying on this method (Nevin, 1992a; 1992b), group data are used to calculate resistance ratios for each disruption condition. Consistent with Figure 3.1, functions have been translated vertically to make comparison of the slopes easier. In previous work (e.g. Nevin, 1992b), progressively larger magnitudes of disruptor were used to ensure a suitably declining slope. In the present study, where different magnitudes of disruptor are being compared, the response rates obtained during disruption did not always produce a declining function. For example, responding sometimes decreased in the first session of disruption only to progressively recover over succeeding sessions (e.g. B2 in Figure 2.8). Because response rate functions of log transformed data from disruption sessions did not always produce slopes that were negative for both components, slope measurements (i.e. the slopes of fitted regression lines) included five days of the average baseline response rate, followed by several sessions of data from disruption conditions. When used with group data, this ensured that response rate functions declined for both components in all conditions.

In Figure 3.2 B, as in Figure 3.2 A, different disruptors produced a range of resistance functions. Table 6 lists the slopes of the resistance functions displayed in Figure 3.2 B.

Table 6.

Slopes of resistance functions obtained in Experiment 1 and presented in Figure 3.2 B. Mass ratios have been calculated using the ratio of slopes method.

Dark-key food VT 30-s	0.411
Dark-key food VT 60-s	0.653
Prefeeding 10%	0.187
Prefeeding 5%	0.011
Extinction	0.128

Although the ratio of slopes method produced more extreme variation in the slopes of resistance functions than the APOB method, these results do not support the conclusions

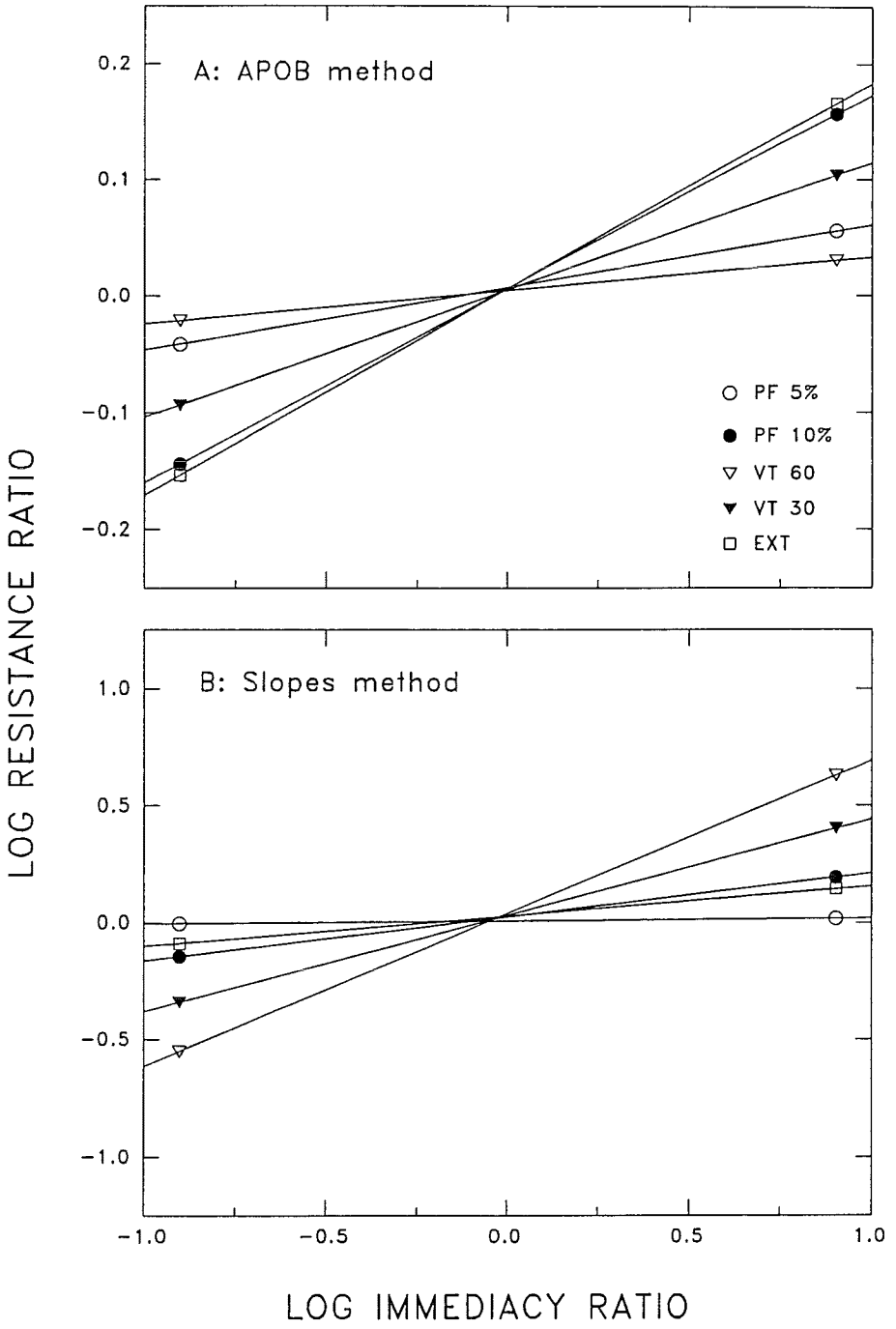

Figure 3.2. Log resistance ratios plotted as a function of log reinforcer immediacy ratios for different types and magnitudes of disruption in Experiment 1. Panels show group results calculated using the APOB method (top panel) and the ratio of slopes method (bottom panel). Note that resistance functions have been arranged so that they share a common intercept. Also, vertical and horizontal axes are unequal and vertical axes differ between panels.

reached using the APOB method. First, using the APOB method, the present study found that the sensitivity of relative resistance to relative reinforcer immediacy was considerably lower than the 0.35 evident in Nevin's summary of previous single-key multiple schedule resistance studies. The average slope of the resistance functions derived using this approach was 0.11. While the use of delayed reinforcement may provide one reason for this effect, when resistance ratios were calculated using the ratio of slopes method the average sensitivity of relative resistance to relative immediacy increased to 0.28, much closer to the 0.35 predicted by previous findings using other reinforcer parameters.

A second consequence of using the ratio of slopes method is that the order evident in Figures 3.1 and 3.2 A disappears. Although Figure 3.2 B shows that there was considerable variation in the slopes of resistance functions when the ratio of slopes method was used, the systematic relationship between disruptor magnitude and relative resistance was not preserved.

In conclusion, when the APOB method is used, results from the present study pose difficulties for Behavioural Momentum Theory. Conversely, when the ratio of slopes method is employed, results are generally consistent with resistance theory and previous findings. Nevertheless, there are good reasons to prefer the conclusions based on the APOB method.

3.4 APOB VERSUS SLOPE.

There are several reasons to prefer the conclusions reached using the APOB method in the present study. First, the ratio of slopes method is not particularly satisfactory in the present study. Second, the ratio of slopes method could easily mask the systematic mass ratio variation obtained using the APOB method. Finally, there is no obvious reason why the results obtained using the APOB method should be the consequence of systematic error.

In the present study, the ratio of slopes method is not particularly satisfactory as a method of data analysis. This method of measuring relative mass normally involves the concatenation of different magnitudes of the disrupting force in order to produce a declining response rate function. This is unsuitable when different magnitudes of disruptor are the object of comparison. Nevertheless, the slopes of response rate functions can still be used to compare

the effects of different magnitudes of disruption by conducting the resistance tests for different magnitudes of disruption in separate trials. However, when this was done in the present study, the production of meaningful slope measurements required the use of group data and the inclusion of several days of baseline data. This provides an approximation of the method employed in recent resistance studies (Nevin, 1992a, 1992b), but doesn't allow comparisons between subjects.

A second reason to prefer the conclusions reached using the APOB method is that as a result of its metric properties, the ratio of slopes method may inadvertently mask systematic mass ratio variation. One way that this could occur is through the production of large mass ratios when disruptor magnitudes are small. When disruptor magnitudes are small, responding is unlikely to decline much and slopes are likely to be shallow. Thus, the rich component may have a slope that is quite close to zero. The lean component may then have a shallow slope that is significantly larger than that of the rich component. For example, the rich component may have a slope of -0.0008, while the lean component has a slope of -0.005. This results in a resistance ratio that is unreasonably large (6.25 in this example), because when both components have changed very little, the resistance ratio should be close to 1.0.

A second way in which the ratio of slopes method might mask systematic variation of mass ratios relates to the way in which the slopes of response rate functions may be affected by variable data. Figure 3.3 shows that relatively small variations in the data can produce changes in the slope of the response rate function. When two unreliable measures of resistance are combined to produce a measure of relative mass, measurement errors translate multiplicatively into large deviations in log resistance ratio. This is a particular problem in the present study, where response rates were often erratic over the course of disruption.

This effect might account for another problem, the significant differences between subjects that can result from the use of the ratio of slopes method. When Nevin (1992b) compared extinction with prefeeding, averaged data from both disruptors were consistent with the quantitative model. Both disruptors produced resistance functions with slopes of close to 0.35. However, Figure 3.4 shows that several birds differed significantly from the group average, and these deviations are not consistent with the quantitative model. Thus, the ratio of slopes

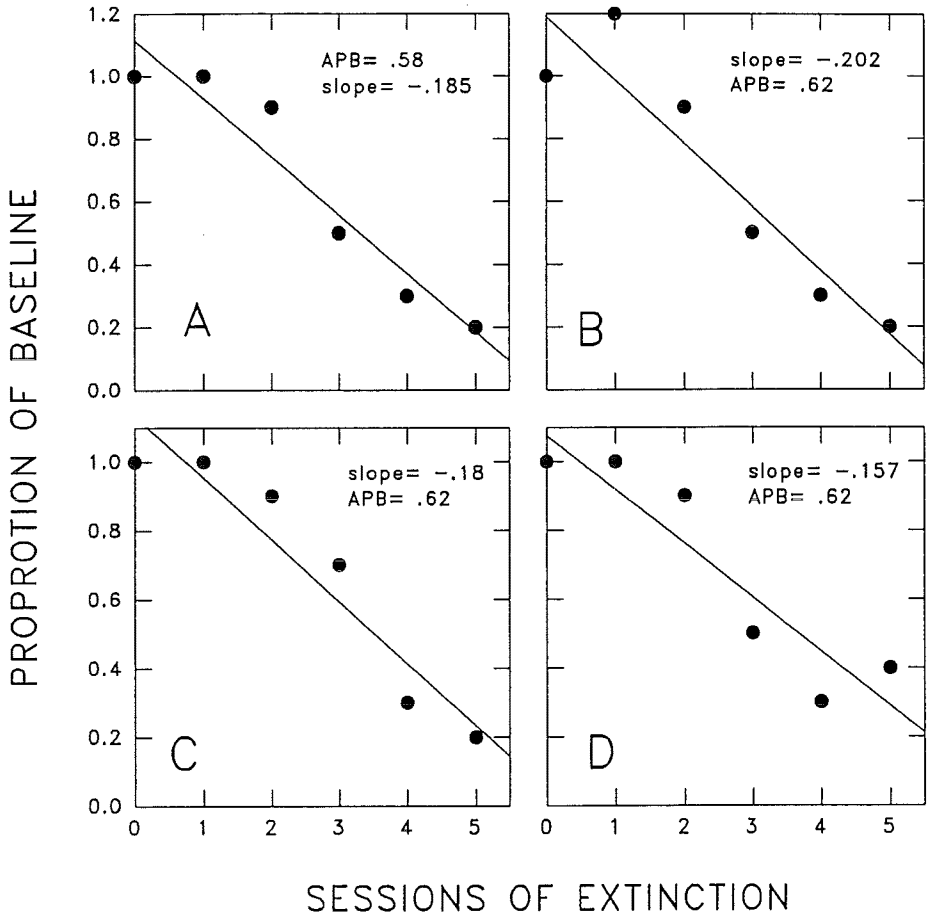

Figure 3.3. Hypothetical resistance data, expressed as proportion of baseline and plotted as a function of sessions of extinction. Panels B, C and D differ from Panel A in that one data point has been varied by the same amount in each panel. The slope of the least-squares regression line and the average proportion of baseline for each data set is given in each panel. Proportions of baseline in the varied panels are constant, while the slopes of fitted regression lines vary.

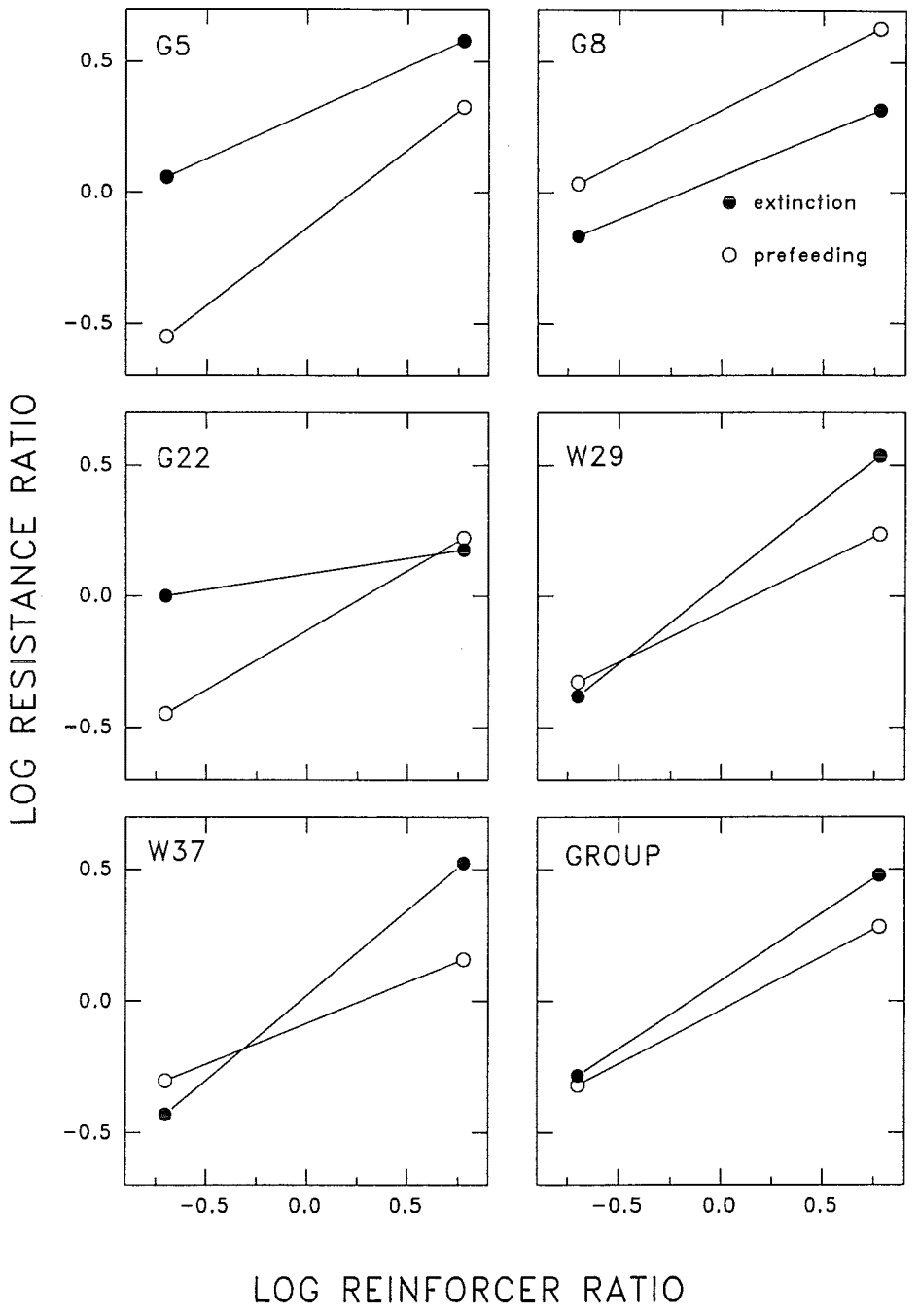

Figure 3.4. Log resistance ratio plotted as a function of log reinforcer ratio for disruption with prefeeding (unfilled circles) and extinction (filled circles) in Nevin 1992b. Resistance ratios have been calculated using the ratio of slopes method.

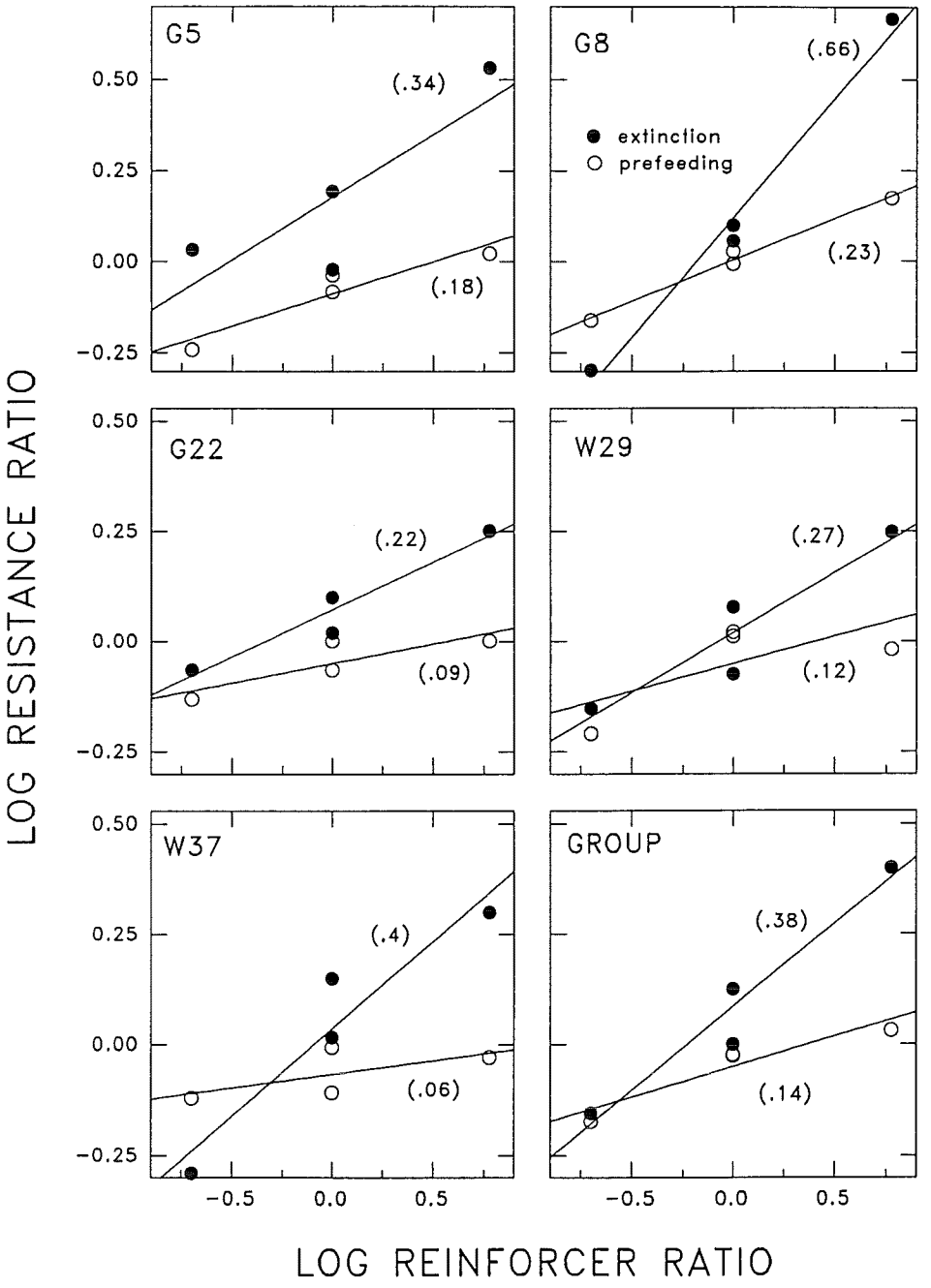

Figure 3.5. Log resistance ratio plotted as a function of log reinforcer ratio for disruption with prefeeding (unfilled circles) and extinction (filled circles) in Nevin 1992b. Resistance ratios have been calculated using the APOB method. The slopes of least-squares regression lines are given in parentheses in each panel.

method is liable to produce variable measures of resistance that only conform to the quantitative analysis in terms of the average result.

In contrast, the APOB method is less susceptible to the effects of noise. Figure 3.3 demonstrates how variable data might affect the slopes of response rate functions. The same figure shows that APOBs are indifferent to sequential effects in the data and are less susceptible to the effects of noise, because small variations do not disproportionately effect the overall result. When this method is applied to Nevin's 1992b data, a quite different effect is observed from that obtained using the ratio of slopes. Figure 3.5 shows that when resistance ratios are calculated using APOBs, the resistance functions obtained from prefeeding are consistently shallower than those obtained using extinction (an example of mass ratio variation that is similar to results in the present study). In addition, all of the subjects demonstrate the pattern observed in the group data.

Some previous momentum research has used something like the APOB method that was employed in the present study. Nevin, Mandell and Yarensky (1981) examined resistance to change in chained multiple schedules, and calculated mass ratios using the weighted mean proportion of baseline in each chain. This was calculated by "multiplying the proportion of baseline at each value of concurrent reinforcement or prefeeding by that value, summing, and dividing by the sum of the concurrent reinforcement or prefeeding values" (p 281). In other words, the raw average proportions of baseline were weighted according to the magnitude of disruption, with larger magnitudes of prefeeding or dark-key food being accorded more weight than small magnitudes. This weighting procedure was adopted because the authors felt that the effects of larger amounts of (say) prefeeding "are likely to be more reliable than the lesser effects of smaller prefeeding amounts" (p 282).

While it is difficult to see how a weighting algorithm could be applied in the present study (where different magnitudes of disruption are the object of comparison), the possibility that the APOBs obtained with smaller magnitudes of disruption are systematically unreliable must be considered. Small magnitudes of disruption might be less reliable than large magnitudes if they yielded small, noisy effects, compared with larger disruptions. However, there are several reasons why this is not a convincing objection to results from the present study.

First, an examination of the data obtained in Experiment 1 indicates that smaller magnitudes of disruption did not necessarily yield rate effects that were noticeably smaller or noisier than those of larger disruptors. Figures 2.7 and 2.8 showed disruption with dark-key food, expressed as proportion of baseline, in both phases of Experiment 1. Although relative resistance was smaller for disruption with VT 60-s than VT 30-s dark-key food, it is clear from these results that both disruptors produced similar reductions in responding, and similar levels of variation in the data. This is especially true for B1 and B2, subjects that produced the strongest differentials in the slopes of resistance functions (Figure 2.9). On the strength of these data, it could not be argued that the different resistance functions, obtained using different magnitudes of disruption, were an artifact of small but noisy reductions in response rate obtained using disruptors of small magnitude.

Second, even if reductions in response rates were noisy when small magnitudes of disruption were applied, noise should be randomly distributed, and as a consequence, unlikely to produce the order evident in Figures 3.1 and 3.2 A. When clean data are randomly varied, APOBs increase or decrease randomly so that the resultant mass ratios are sometimes larger than, and sometimes smaller than the mass ratio obtained using clean data. Relatedly, random noise should not have much effect on summed results. In the present study, the summed results in Figure 3.2 A are clearly representative of the results for individual subjects in Figure 3.1. This also suggests that individual data obtained using the APOB method with disruptors of small magnitude were not adversely affected by noise.

Considering the results of the present study, there seem to be no reasons why proportions of baseline responding should be weighted. Instead, there are reasons to avoid weighting. The present study suggests that different magnitudes of disruptor produce different resistance functions, and that measures of relative resistance to change are therefore dependent upon the magnitude of disruptor that is applied. It follows that studies which concatenate and differentially weight different magnitudes of disruption to calculate resistance ratios (Nevin, Mandell and Yarensky, 1981; Nevin et al, 1983; Nevin, 1992b; Cohen, Riley and Weigle, 1993) are unreliable because their results, are in a sense, multiply confounded.

A second reason for not weighting APOBs is that this method is not appropriate when extinction is used as a disruptor. Weighting "larger magnitudes" of extinction involves giving more weight to the later sessions of extinction (Nevin et al, 1983, p 50). However, resistance ratios based on proportions of baseline can become unstable after prolonged extinction. When response rates become very low, resistance ratios can vary unsystematically over a wide range. Unweighted APOBs absorb these irregularities without according them undue significance, because these small values do not have much effect on the average result.

To conclude, there are several reasons to accept the conclusions reached in the present study using the APOB method. The ratio of slopes method is susceptible to the effects of variable data, produces extreme mass ratios when reductions in responding are small, and fails to produce consistency between subjects. Thus, the ratio of slopes method produces noisy results that are capable of concealing the systematic variations in mass ratio that were revealed using the APOB method. In contrast, the use of APOBs produces results that are consistent between subjects, and although this method does not support the assumption of mass ratio invariance, there is no obvious reason why this finding should be the result of systematic error when small disruptors are used. Moreover, mass ratio variance, when different magnitudes of disruption are used, is predicted by the Quantitative Law of Effect.

3.5 MASS RATIOS, DISRUPTOR MAGNITUDE AND THE QUANTITATIVE LAW OF EFFECT.

The relationship between mass ratio and the magnitude of disruption that was produced using the APOB method in the present study is not consistent with Behavioural Momentum Theory, however, it is predicted by the Quantitative Law of Effect. The Quantitative Law of Effect describes steady-state operant behaviour in terms of Herrnstein's (1970, 1974) matching relation. In single schedules, a rate of response (P) is predicted by the equation;

$$P = kR / R+R_O. \qquad (1)$$

In this equation k represents the total behaviour occurring in the session, R represents scheduled reinforcement, and R_0 represents alternative or 'extraneous' reinforcement (Herrnstein, 1970, p 255). When applied to multiple, rather than single schedules, Herrnstein (p 259) proposed that the rate of responding in a component (P1) be described by the equation;

$$P_1 = kR_1 / R_1 + mR_2 + R_0. \qquad (2)$$

More simply, and based on the proposition that behavioural contrast occurs when extraneous reinforcers are 'reallocated' between the multiple schedule components (McLean and White, 1983; McLean, 1992), Equation 2 can be expressed in the form;

$$P_1 = kR_1 / R_1 + R_0. \qquad (3)$$

When this model is applied to multiple schedule resistance research, the effects of disruption can be construed as an increase in the value of extraneous reinforcement (R_0) (Nevin, 1992b, p 127). Figure 1.3 showed that when Equation 3 is applied to two components in a multiple schedule, and when disruption is construed as proportional increases in R_0, not only is the richer component most resistant to change, but mass ratios (measured using the APOB method) increase as R_0 gets larger.

Nevin (1992b) has considered the question of whether the Quantitative Law of Effect is an adequate description of resistance to change, and concluded that this is not the case. According to Nevin, the Quantitative Law of Effect and Behavioural Momentum Theory make different predictions when resistance is tested in two components (1 and 2) across conditions in which Component 1 is varied so that the rate of reinforcement is either higher (Condition A) or lower (Condition B) than in the constant component (Component 2). Nevin argues that the Quantitative Law of Effect predicts that "resistance to change in the constant component should be greater in condition A than in condition B" (Nevin, 1992b, p 127) but that "the opposite expectation follows from the view that resistance to change....depends on the stimulus-reinforcer contingency established during baseline training". Thus, from this point of view, Behavioural Momentum Theory and the Quantitative Law of Effect make opposite predictions when one component is held constant while the other is varied. However, this is not necessarily true, and if R_0 is allocated unequally between components, the Quantitative Law of Effect and Behavioural Momentum Theory make the same predictions in the situation Nevin describes.

A recent study (McLean, 1992), in which extraneous reinforcers were measured during the course of an otherwise conventional multiple schedule, demonstrated that R_0 was unequally distributed between multiple schedule components that differed in rate of reinforcement. In this experiment, rate of reinforcement in one component remained constant across conditions while the other was varied. 'Extraneous' reinforcers were freely available on a second key throughout each experimental session. To simulate the way in which alternative responding might produce extraneous reinforcers, the 'extra' key delivered reinforcers according to a conjoint schedule comprising five overlapping VI schedules and one VR schedule. Rates of extra-key reinforcement during the varied component bore an inverse relationship with reinforcement rate on the main key during that component. This implies that R_0 varies inversely with scheduled reinforcement, and therefore, that rich components should have lower values of R_0 than lean ones. Thus, any quantitative analysis of multiple schedules, such as that proposed by Nevin (1992b), should recognise that R_0 will be unequally allocated between components that have different values of reinforcement.

As the following example makes clear, when the values of R_0 differ between components, the Quantitative Law of Effect and Behavioural Momentum Theory make the same predictions in the situation Nevin describes. Using Equation 3 and giving k a value of 100, baseline response rates are:

Condition A:

Constant component: P = 100x60 / 60+30 = 67 responses/minute

Varied component: P = 100x300 / 300+10 = 97 responses/minute

Condition B:

Constant component: P = 100x60 / 60+15 = 80 responses/minute

Varied component: P = 100x10 / 10+25 = 29 responses/minute

Disruption can be construed as a proportional increase in the value of R_0, and supposing that disruption increases the value of R_0 by a factor of five, response rates, and proportions of baseline responding are:

Condition A:

Constant component: P = 100x60 / 60+150 = 29 responses/minute (43% of baseline)

Varied component: P = 100x300 / 300+50 = 86 responses/minute (88% of baseline)

Condition B:

Constant component: P = 100x60 / 60+75 = 44 responses/minute (56% of baseline)

Varied component: P = 100x10 / 10+125 = 7 responses/minute (26% of baseline)

As indicated in this example, in Condition A, a disruptor (construed as an increase in R_0) reduces the response rate in the constant component to 43 percent of baseline, whereas in Condition B, response rate in the constant component reduces to 56 percent of baseline. Thus, the constant component is most resistant to change in the condition where the stimulus-reinforcer contingency for this component is strongest.

This quantitative analysis is consistent with both of the predictions made by Behavioural Momentum Theory. First, the rich component is most resistant to the effects of disruption in both conditions, and second, the constant component is more resistant to change in Condition B than in Condition A. Therefore, when differential allocation of R_0 is assumed, the Quantitative Law of Effect appears to provide an adequate account of resistance to change in single-key multiple schedules. That this model predicts the relationship between mass ratio and disruptor magnitude that was obtained in the present study is particularly interesting.

Herrnstein's equation is typically applied to the study of steady state responding. However, as shown here, the Quantitative Law of Effect seems to deal adequately with resistance to change effects that occur on a more short-term basis. As Nevin has recognised, this is problematic for Behavioural Momentum Theory. If steady-state responding and resistance to

change can be explained by the Quantitative Law of Effect, "there may be no need to distinguish the velocity- and mass-like aspects of behaviour" (Nevin, 1992b, p 127). While the model presented here makes predictions that are consistent with the findings obtained using the APOB method in the present study, this account remains speculative, and the distribution of extraneous reinforcement in resistance to change procedures requires investigation.

3.6 SUMMARY AND CONCLUSIONS.

The present study successfully replicated findings from previous work (Nevin, 1974) that used delayed reinforcement to investigate relative resistance to change in multiple schedules. In Experiments 1 and 2, with few exceptions, responding was most resistant to disruption in the component maintained by short (1 second) reinforcement delays. This was true for two different methods of data analysis, and is consistent with Behavioural Momentum Theory.

However, when resistance ratios were calculated using the APOB method, resistance sensitivity was much lower than 0.35, and the mass ratio invariance assumption was not supported. Instead, an orderly relationship emerged between mass ratio and magnitude of disruption. In contrast, when resistance ratios were calculated using the ratio of slopes method, results from the present study fell comfortably within the range of data obtained from previous resistance studies. From this point of view then, resistance data obtained using delayed reinforcement were quite consistent with those obtained using reinforcer rate and magnitude, summarised by Nevin (1992a) using the same computation.

In the present study, whether the mass ratio invariance assumption is supported or not depends entirely on which method of data analysis is used. Nevertheless, if the assumption is true, then the APOB method must produce error that systematically underestimates resistance ratios when disruptor magnitudes are small. It is not immediately apparent just how a systematic error of this type could occur. For the mass ratio invariance assumption to be false, there must be some reason why this effect is not apparent when the ratio of slopes method is

used to calculate relative resistance. The ratio of slopes method has metric properties that could explain the variability, and lack of systematic effect that results when this method is used. Not only is this approach susceptible to the effects of variable data, it produces extreme mass ratios when disruptors are small.

In the absence of some explanation as to how the mass ratio variance obtained using the APOB method could be the result of systematic error, and because the ratio of slopes method can easily conceal this effect by swamping it with variability in mass ratio estimates, the results from the present study are at least suggestive of a relationship between disruptor magnitude and relative resistance. The method of analysis currently used in resistance research may mask effects that have important theoretical implications, but despite this, the ratio of slopes method does have the advantage of supporting an economical theory. Ultimately, choosing between these methods may depend upon theoretical considerations that are external to the analytical issues.

From another point of view, there is some reason to expect that larger disruptors should produce larger mass ratios and steeper resistance functions. The effects of disruption can be analysed in terms of the Quantitative Law of Effect describing multiple schedule performance (de Villiers and Herrnstein, 1976; Herrnstein, 1970; McLean and White, 1983). From this perspective, disruption can be viewed as an increase in the value of extraneous reinforcement in each component. When the effects of disruption are interpreted in this way, the Quantitative Law of Effect, like Behavioural Momentum Theory, predicts that resistance will be greatest in the richer of two components. Interestingly, this analysis also predicts increases in mass ratio when the magnitude of disruption is increased. Increases in the value of extraneous reinforcement exert more force on a lean component than a rich one, because extraneous reinforcement comprises a larger proportion of the total reinforcement in lean components. This is exactly what is needed to explain the results obtained using APOBs in the present study.

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APPENDIX ONE

Appendix 1 presents complete data for all subjects in Experiment 1. Results for each disruption are listed with baseline data (BL) shown first and data from disruption sessions shown subsequently. Columns show responses per minute in Component 1 (P1) and Component 2 (P2), standard deviations for baseline response rates (SD) in the two components, reinforcers per hour in Component 1 (R1), Component 2 (R2) and the intercomponent interval (R3), and the proportions of baseline responding in Component 1 (POB1) and Component 2 (POB2) during sessions of disruption.

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B1 PHASE ONE									
Prefeeding 5%									
BL	57.45	5.54	45.86	4.06	27.86	30.86	0.00		
	38.50		21.71		17.14	38.57	0.00	0.67	0.47
Extinction									
BL	50.19	2.47	41.48	4.92	35.14	34.71	0.00		
	34.79		22.50		0.00	0.00	0.00	0.69	0.54
	24.29		7.57		0.00	0.00	0.00	0.48	0.18
	16.86		6.29		0.00	0.00	0.00	0.34	0.15
	0.71		0.00		0.00	0.00	0.00	0.01	0.00
	8.00		4.64		0.00	0.00	0.00	0.16	0.11
	0.14		0.00		0.00	0.00	0.00	0.00	0.00
	13.57		6.93		0.00	0.00	0.00	0.27	0.17
	2.07		0.00		0.00	0.00	0.00	0.04	0.00
	0.00		0.00		0.00	0.00	0.00	0.00	0.00
VT 30-s dark-key food									
BL	44.76	3.83	39.51	6.14	32.57	33.00	0.00		
	40.29		38.29		21.43	34.29	111.43	0.90	0.97
	39.36		18.14		42.86	30.00	111.43	0.88	0.46
	36.21		18.64		25.71	21.43	128.57	0.81	0.47
	39.07		18.14		21.43	42.86	111.43	0.87	0.46
	32.71		17.29		38.57	34.29	128.57	0.73	0.44
	28.36		14.07		21.43	21.43	115.71	0.63	0.36
	36.00		18.43		30.00	34.29	115.71	0.80	0.47
	34.86		15.79		25.71	38.57	107.14	0.78	0.40
	33.93		18.50		38.57	30.00	120.00	0.76	0.47
	26.21		20.29		25.71	34.29	120.00	0.59	0.51
VT 60-s dark-key food									
BL	33.07	6.00	31.49	5.35	29.57	29.57	0.00		
	41.14		23.29		38.57	38.57	55.71	1.24	0.74
	33.14		20.50		38.57	38.57	55.71	1.00	0.65
	24.07		16.36		38.57	30.00	51.43	0.73	0.52
	24.36		18.79		17.14	30.00	60.00	0.74	0.60
	27.50		19.36		25.71	42.86	55.71	0.83	0.62
	30.50		21.71		34.29	25.71	51.43	0.92	0.69
	27.71		19.43		42.86	25.71	55.71	0.84	0.62
	24.71		22.29		21.43	34.29	55.71	0.75	0.71
	30.21		20.00		34.29	34.29	51.43	0.91	0.64
	24.14		18.57		42.86	30.00	51.43	0.73	0.59
	24.00		16.93		34.29	34.29	51.43	0.73	0.54
	25.36		22.21		30.00	38.57	51.43	0.77	0.71
Prefeeding 10%									
BL	27.89	2.19	34.89	2.99	30.00	35.57	3.86		
	20.00		17.29		25.71	25.71	0.00	0.72	0.50

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B1 PHASE TWO (REVERSAL)									
Prefeeding 5%									
BL	32.00	1.87	42.32	2.92	32.57	35.14	0.00		
	30.93		38.71		47.14	17.14	0.00	0.97	0.92
Prefeeding 10%									
BL	37.11	3.17	38.89	4.34	34.29	27.00	0.00		
	33.86		37.64		12.86	38.57	0.00	0.91	0.97
	22.21		26.86		21.43	38.57	0.00	0.60	0.69
	5.43		7.43		17.14	21.43	0.00	0.15	0.19
VT 60-s dark-key food									
BL	41.83	4.16	43.44	3.61	32.14	32.57	0.00		
	32.07		29.79		25.71	34.29	55.71	0.77	0.69
	27.71		29.14		30.00	38.57	55.71	0.66	0.67
	20.00		21.29		34.29	30.00	55.71	0.48	0.49
	20.43		21.50		42.86	34.29	60.00	0.49	0.50
	19.64		22.79		25.71	25.71	51.43	0.47	0.53
	22.57		25.71		38.57	42.86	60.00	0.54	0.59
	23.00		31.14		34.29	30.00	55.71	0.55	0.72
	24.21		26.50		34.29	25.71	51.43	0.58	0.61
	19.57		20.79		17.14	17.14	51.43	0.47	0.48
	22.29		23.36		34.29	34.29	60.00	0.53	0.54
VT 30-s dark key food									
BL	44.35	2.32	37.01	2.52	30.00	33.43	0.00		
	27.71		24.43		30.00	38.57	111.43	0.63	0.66
	21.79		19.93		25.71	30.00	120.00	0.49	0.54
	22.57		20.43		17.14	34.29	102.86	0.51	0.55
	21.00		24.57		21.43	38.57	111.43	0.47	0.66
	20.93		23.86		21.43	42.86	111.43	0.47	0.65
	22.79		24.86		21.43	30.00	107.14	0.51	0.67
	19.07		18.14		34.29	30.00	111.43	0.43	0.49
	13.64		19.00		25.71	30.00	107.14	0.31	0.51
	14.93		24.29		21.43	30.00	115.71	0.34	0.66
	17.93		27.64		34.29	38.57	120.00	0.40	0.75
Extinction									
BL	37.18	5.49	37.74	4.44	36.00	30.43	0.00		
	23.86		32.14		0.00	0.00	0.00	0.64	0.85
	22.79		28.93		0.00	0.00	0.00	0.61	0.77
	16.36		36.29		0.00	0.00	0.00	0.44	0.96
	16.14		35.21		0.00	0.00	0.00	0.43	0.93
	15.93		35.79		0.00	0.00	0.00	0.43	0.95
	9.64		17.93		0.00	0.00	0.00	0.26	0.48
	3.50		15.07		0.00	0.00	0.00	0.09	0.40
	0.00		4.71		0.00	0.00	0.00	0.00	0.13
	2.29		2.79		0.00	0.00	0.00	0.06	0.07

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B2 PHASE ONE									
Prefeeding 10%									
BL	73.09	5.95	81.78	5.23	34.29	31.29	0.00		
	17.07		9.14		21.43	25.71	0.00	0.23	0.11
Prefeeding 5%									
BL	76.99	3.03	75.20	8.20	35.57	34.71	0.00		
	73.79		56.29		30.00	34.29	0.00	0.96	0.75
Prefeeding 10%									
BL	81.24	6.37	68.24	5.20	35.14	33.00	0.00		
	52.93		23.50		34.29	38.57	0.00	0.65	0.34
Prefeeding 5%									
BL	79.27	7.44	62.45	4.83	30.86	31.29	0.00		
	84.93		57.14		30.00	42.86	0.00	1.07	0.92
Extinction									
BL	89.64	5.69	74.61	7.05	29.57	30.43	0.00		
	87.79		55.57		0.00	0.00	0.00	0.98	0.75
	77.14		63.64		0.00	0.00	0.00	0.86	0.85
	70.93		56.21		0.00	0.00	0.00	0.79	0.75
	67.07		37.86		0.00	0.00	0.00	0.75	0.51
	57.29		27.57		0.00	0.00	0.00	0.64	0.37
	57.57		18.36		0.00	0.00	0.00	0.64	0.25
	47.86		38.50		0.00	0.00	0.00	0.53	0.52
	33.00		14.36		0.00	0.00	0.00	0.37	0.19
	11.14		8.29		0.00	0.00	0.00	0.12	0.11
VT 30-s dark-key food									
BL	102.40	5.31	80.70	4.22	30.86	30.00	0.00		
	86.71		54.29		34.29	25.71	111.43	0.85	0.67
	87.43		47.50		38.57	25.71	111.43	0.85	0.59
	83.71		38.50		34.29	38.57	120.00	0.82	0.48
	79.71		47.57		21.43	21.43	107.14	0.78	0.59
	66.86		37.50		30.00	30.00	124.29	0.65	0.47
	90.71		34.57		21.43	30.00	111.43	0.89	0.43
	82.86		38.71		34.29	42.86	102.86	0.81	0.48
	92.79		33.43		21.43	25.71	120.00	0.91	0.41
	81.93		36.29		30.00	34.29	115.71	0.80	0.45
	84.14		45.71		38.57	21.43	115.71	0.82	0.57
VT 60-s dark-key food									
BL	97.81	7.71	74.74	9.52	37.39	33.00	3.43		
	87.36		57.00		34.29	38.57	55.71	0.89	0.79
	86.86		57.29		25.71	30.00	60.00	0.89	0.80
	93.79		48.86		30.00	17.14	60.00	0.96	0.68
	86.14		59.21		34.29	30.00	51.43	0.88	0.82
	86.00		65.29		25.71	42.86	55.71	0.88	0.91
	89.64		52.14		25.71	34.29	55.71	0.92	0.72
	86.86		65.07		25.71	42.86	51.43	0.89	0.90
	90.79		41.57		25.71	38.57	60.00	0.93	0.58
	92.07		51.21		38.57	25.71	60.00	0.94	0.71
	104.90		36.29		21.43	17.14	60.00	1.07	0.50
	88.93		46.64		21.43	30.00	0.00	0.91	0.65
	95.21		52.43		25.71	34.29	64.29	0.97	0.73
Houselight									
BL	92.46	4.83	78.39	5.54	34.29	35.57	0.00		
	75.14		56.71		30.00	21.43	0.00	0.81	0.72
	77.29		60.21		30.00	21.43	0.00	0.84	0.77
	85.14		59.21		42.86	42.86	0.00	0.92	0.76
	80.29		58.64		42.86	21.43	0.00	0.87	0.75

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B2 PHASE TWO (REVERSAL)									
Prefeeding 5%									
BL	80.83	6.68	94.84	2.89	34.29	32.14	0.00		
	84.43		90.50		25.71	38.57	0.00	1.05	0.95
Prefeeding 10%									
BL	84.05	9.18	96.73	6.09	34.71	34.71	0.00		
	54.00		86.21		30.00	21.43	0.00	0.64	0.89
	46.71		66.50		21.43	30.00	0.00	0.56	0.69
	53.50		82.79		25.71	21.43	0.00	0.64	0.86
VT 60-s dark-key food									
BL	77.44	4.54	98.13	3.79	33.00	32.14	0.00		
	68.36		80.21		30.00	38.57	51.43	0.88	0.82
	66.79		84.50		25.71	17.14	55.71	0.86	0.86
	56.43		86.36		30.00	34.29	60.00	0.73	0.88
	71.71		92.86		21.43	25.71	60.00	0.93	0.95
	73.21		99.57		30.00	30.00	60.00	0.95	1.02
	71.00		104.14		34.29	30.00	55.71	0.92	1.06
	66.36		103.50		25.71	42.86	51.43	0.86	1.06
	69.29		101.29		30.00	25.71	55.71	0.90	1.03
	66.71		107.07		30.00	30.00	51.43	0.86	1.09
	74.43		112.14		25.71	34.29	55.71	0.96	1.14
VT 30-s dark-key food									
BL	74.96	4.16	97.41	6.30	32.14	33.00	0.00		
	34.57		85.36		34.29	34.29	111.43	0.46	0.88
	41.43		88.71		30.00	25.71	107.14	0.55	0.91
	39.93		90.36		34.29	38.57	111.43	0.53	0.93
	49.71		92.64		30.00	42.86	111.43	0.66	0.95
	54.36		86.71		30.00	25.71	111.43	0.73	0.89
	50.07		88.50		17.14	34.29	124.29	0.67	0.91
	51.64		92.36		30.00	34.29	120.00	0.69	0.95
	47.07		94.43		30.00	34.29	107.14	0.63	0.97
	55.79		92.57		38.57	21.43	111.43	0.74	0.95
	50.64		79.86		30.00	30.00	107.14	0.68	0.82
Extinction									
BL	75.55	3.53	96.54	3.74	27.86	34.29	0.00		
	74.29		100.43		0.00	0.00	0.00	0.98	1.04
	66.93		103.07		0.00	0.00	0.00	0.89	1.07
	45.57		86.36		0.00	0.00	0.00	0.60	0.89
	36.14		69.79		0.00	0.00	0.00	0.48	0.72
	24.57		59.93		0.00	0.00	0.00	0.33	0.62
	23.14		56.29		0.00	0.00	0.00	0.31	0.58
	8.57		34.00		0.00	0.00	0.00	0.11	0.35
	25.93		45.14		0.00	0.00	0.00	0.34	0.47
	0.86		9.14		0.00	0.00	0.00	0.01	0.10

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B3	**PHASE ONE**								
Prefeeding 10%									
BL	52.96	7.86	31.11	6.51	31.29	29.57	0.00		
	11.07		3.14		25.71	12.86	0.00	0.21	0.10
Prefeeding 5%									
BL	64.04	7.36	45.37	9.68	30.00	32.57	0.00		
	38.71		18.79		38.57	21.43	0.00	0.61	0.41
Prefeeding 10%									
BL	39.02	14.61	20.37	10.14	26.57	26.57	0.00		
	4.64		0.86		21.43	12.86	0.00	0.12	0.04
Prefeeding 5%									
BL	48.96	12.51	28.56	11.14	32.57	26.57	0.00		
	3.00		0.21		17.14	4.29	0.00	0.06	0.01
Extinction									
BL	53.14	11.11	25.82	7.99	29.14	26.57	0.00		
	23.50		10.86		0.00	0.00	0.00	0.44	0.42
	9.93		3.29		0.00	0.00	0.00	0.19	0.13
	3.43		0.64		0.00	0.00	0.00	0.07	0.03
	5.71		0.79		0.00	0.00	0.00	0.11	0.03
	1.36		0.36		0.00	0.00	0.00	0.03	0.01
	0.00		0.00		0.00	0.00	0.00	0.00	0.00
	0.71		1.36		0.00	0.00	0.00	0.01	0.05
	3.00		1.29		0.00	0.00	0.00	0.06	0.05
	0.14		0.29		0.00	0.00	0.00	0.00	0.01
VT 30-s dark-key food									
BL	54.17	4.72	26.51	7.48	27.00	33.00	0.00		
	40.43		23.93		25.71	42.86	115.71	0.75	0.90
	40.57		20.50		34.29	21.43	107.14	0.75	0.77
	41.00		20.79		34.29	34.29	107.14	0.76	0.78
	32.93		29.07		21.43	25.71	115.71	0.61	1.10
	39.00		23.29		42.86	42.86	107.14	0.72	0.88
	30.14		20.57		34.29	30.00	115.71	0.56	0.78
	31.29		9.71		17.14	25.71	107.14	0.58	0.37
	31.50		12.57		38.57	25.71	107.14	0.58	0.47
	40.43		20.71		42.86	38.57	120.00	0.75	0.78
	27.50		12.14		34.29	42.86	120.00	0.51	0.46
VT 60-s dark-key food									
BL	50.18	16.60	30.94	14.07	28.29	27.00	0.00		
	47.57		28.14		34.29	34.29	60.00	0.95	0.91
	58.50		44.86		25.71	25.71	60.00	1.17	1.45
	47.43		40.43		38.57	38.57	55.71	0.95	1.31
	38.43		33.86		34.29	21.43	55.71	0.77	1.09
	52.93		43.93		30.00	30.00	55.71	1.06	1.42
	44.64		30.64		38.57	30.00	55.71	0.89	0.99
	48.93		26.93		42.86	21.43	51.43	0.98	0.87
	45.00		42.43		38.57	38.57	55.71	0.90	1.37
	45.93		34.43		21.43	38.57	60.00	0.92	1.11
	45.14		26.57		21.43	30.00	55.71	0.90	0.86
	42.64		21.86		30.00	25.71	55.71	0.85	0.71
	45.71		42.14		30.00	34.29	51.43	0.91	1.36
Houselight									
BL	61.36	13.62	38.39	13.26	30.86	31.71	0.00		
	56.86		30.79		25.71	34.29	0.00	0.93	0.80
	54.50		38.64		38.57	38.57	0.00	0.89	1.01
	65.79		40.00		38.57	25.71	0.00	1.07	1.04
	57.79		38.43		38.57	38.57	0.00	0.94	1.00

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B3 PHASE TWO (REVERSAL)									
Prefeeding 5%									
BL	56.94	9.22	67.62	10.15	33.86	29.57	0.00		
	27.79		28.14		25.71	34.29	0.00	0.49	0.42
Prefeeding 10%									
BL	34.61	8.38	42.07	12.29	36.00	31.29	0.00		
	22.93		21.14		25.71	42.86	0.00	0.66	0.50
	5.64		9.29		17.14	17.14	0.00	0.16	0.22
	3.64		3.79		17.14	30.00	0.00	0.11	0.09
VT 60-s dark-key food									
BL	35.59	6.06	51.24	7.66	26.57	33.86	0.00		
	26.07		33.21		21.43	30.00	60.00	0.73	0.65
	26.57		48.71		34.29	42.86	60.00	0.75	0.95
	29.14		30.93		42.86	42.86	68.57	0.82	0.60
	32.57		43.29		34.29	34.29	55.71	0.92	0.85
	38.93		32.07		25.71	30.00	60.00	1.09	0.63
	39.71		40.43		42.86	42.86	55.71	1.12	0.79
	39.43		49.07		38.57	47.14	60.00	1.11	0.96
	37.36		30.21		42.86	21.43	55.71	1.05	0.59
	21.57		34.21		17.14	21.43	60.00	0.61	0.67
	28.86		32.57		30.00	30.00	60.00	0.81	0.64
VT 30-s dark-key food									
	48.44	8.46	55.29	5.65	33.43	33.00	0.00		
	36.71		35.21		34.29	21.43	111.43	0.76	0.64
	25.43		29.79		21.43	42.86	107.14	0.53	0.54
	29.43		36.29		21.43	25.71	107.14	0.61	0.66
	24.64		28.64		38.57	34.29	124.29	0.51	0.52
	24.36		40.86		30.00	38.57	115.71	0.50	0.74
	30.64		38.43		21.43	34.29	111.43	0.63	0.70
	27.71		41.21		34.29	34.29	111.43	0.57	0.75
	27.29		40.93		30.00	38.57	120.00	0.56	0.74
	37.29		38.71		30.00	30.00	120.00	0.77	0.70
	31.14		42.00		25.71	34.29	111.43	0.64	0.76
Extinction									
BL	45.89	7.44	59.28	3.99	30.86	29.14	0.00		
	34.50		67.50		0.00	0.00	0.00	0.75	1.14
	28.57		54.86		0.00	0.00	0.00	0.62	0.93
	4.50		15.43		0.00	0.00	0.00	0.10	0.26
	4.86		16.43		0.00	0.00	0.00	0.11	0.28
	4.64		5.29		0.00	0.00	0.00	0.10	0.09
	2.36		3.86		0.00	0.00	0.00	0.05	0.07
	0.50		2.14		0.00	0.00	0.00	0.01	0.04
	1.14		0.50		0.00	0.00	0.00	0.03	0.01
	2.00		3.29		0.00	0.00	0.00	0.04	0.06

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B4 PHASE 0NE									
Prefeeding 10%									
BL	27.52	4.15	21.47	3.91	27.43	25.29	0.00		
	19.14		3.86		25.71	17.14	0.00	0.70	0.18
Prefeeding 5%									
BL	31.54	7.00	25.29	5.31	31.71	30.00	0.00		
	15.86		10.36		30.00	21.43	0.00	0.50	0.41
Prefeeding 10%									
BL	29.19	5.89	20.24	5.29	30.00	30.43	0.00		
	7.00		1.79		0.00	0.00	0.00	0.24	0.09
Prefeeding 5%									
BL	34.71	5.10	26.02	4.70	30.43	24.43	0.00		
	12.57		6.86		17.14	8.57	0.00	0.36	0.26
Extinction									
BL	25.99	6.99	18.38	4.79	31.29	27.86	0.00		
	13.79		4.79		0.00	0.00	0.00	0.53	0.26
	13.50		9.36		0.00	0.00	0.00	0.52	0.51
	9.14		3.86		0.00	0.00	0.00	0.35	0.21
	1.71		1.57		0.00	0.00	0.00	0.07	0.09
	2.14		1.64		0.00	0.00	0.00	0.08	0.09
	3.64		4.93		0.00	0.00	0.00	0.14	0.27
	2.43		1.36		0.00	0.00	0.00	0.09	0.07
	5.93		1.00		0.00	0.00	0.00	0.23	0.05
	0.00		0.00		0.00	0.00	0.00	0.00	0.00
VT 30-s dark-key food									
BL	34.46	8.63	25.28	7.42	30.43	31.29	0.00		
	44.36		40.29		38.57	34.29	115.71	1.29	1.59
	42.71		30.14		42.86	30.00	120.00	1.24	1.19
	40.36		26.93		30.00	42.86	107.14	1.17	1.07
	38.00		25.29		30.00	17.14	111.43	1.10	1.00
	40.36		24.00		38.57	34.29	115.71	1.17	0.95
	32.00		24.93		34.29	30.00	102.86	0.93	0.99
	28.36		25.86		30.00	17.14	120.00	0.82	1.02
	25.50		19.50		25.71	30.00	111.43	0.74	0.77
	32.93		18.93		34.29	25.71	115.71	0.96	0.75
	26.79		16.21		17.14	38.57	124.29	0.78	0.64
VT 60-s dark-key food									
BL	39.39	8.40	34.18	9.34	25.71	29.57	0.00		
	33.07		26.86		30.00	17.14	60.00	0.84	0.79
	25.29		24.36		34.29	38.57	51.43	0.64	0.71
	24.29		24.43		38.57	47.14	64.29	0.62	0.72
	27.57		24.07		38.57	25.71	51.43	0.70	0.70
	41.71		28.21		30.00	30.00	60.00	1.06	0.83
	50.43		34.64		38.57	38.57	51.43	1.28	1.01
	54.14		37.93		38.57	21.43	55.71	1.37	1.11
	52.79		35.00		34.29	21.43	60.00	1.34	1.02
	55.86		35.00		30.00	25.71	51.43	1.42	1.02
	40.71		39.00		30.00	47.14	51.43	1.03	1.14
	59.07		40.71		38.57	30.00	51.43	1.50	1.19
	53.43		35.86		17.14	38.57	60.00	1.36	1.05
Houselight									
BL	30.36	4.89	29.49	6.00	30.00	29.14	0.00		
	40.93		37.86		42.86	42.86	0.00	1.35	1.28
	52.43		49.71		25.71	30.00	0.00	1.73	1.69
	46.64		43.86		21.43	34.29	0.00	1.54	1.49
	49.93		35.86		42.86	25.71	0.00	1.65	1.22

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
B4 PHASE TWO (REVERSAL)									
Prefeeding 5%									
BL	47.11	9.28	50.76	7.84	35.14	35.14	0.00		
	33.79		34.57		38.57	30.00	0.00	0.72	0.68
Prefeeding 10%									
BL	41.99	14.00	49.05	9.02	30.00	27.86	0.00		
	9.86		7.29		8.57	4.29	0.00	0.24	0.15
	4.00		8.64		12.86	12.86	0.00	0.10	0.18
	1.93		2.21		4.29	8.57	0.00	0.05	0.05
VT 60-s dark-key food									
BL	32.01	3.91	39.94	7.54	32.57	37.71	0.00		
	23.29		34.21		25.71	42.86	60.00	0.73	0.86
	18.93		26.50		47.14	25.71	55.71	0.59	0.66
	15.50		24.07		21.43	21.43	68.57	0.48	0.60
	18.14		31.14		42.86	42.86	51.43	0.57	0.78
	23.93		29.64		25.71	38.57	51.43	0.75	0.74
	22.50		24.86		25.71	21.43	55.71	0.70	0.62
	26.50		32.93		21.43	25.71	55.71	0.83	0.83
	28.50		35.21		38.57	38.57	55.71	0.89	0.88
	30.79		34.64		38.57	34.29	51.43	0.96	0.87
	29.07		36.07		38.57	30.00	60.00	0.91	0.90
VT 30-s dark-key food									
BL	36.06	6.42	38.31	7.12	26.57	34.29	0.00		
	22.86		32.36		38.57	17.14	115.71	0.63	0.85
	27.29		31.00		21.43	30.00	124.29	0.76	0.81
	24.14		29.00		38.57	25.71	102.86	0.67	0.76
	22.86		25.21		25.71	38.57	111.43	0.63	0.66
	18.00		30.00		42.86	17.14	111.43	0.50	0.78
	20.71		27.79		21.43	34.29	107.14	0.57	0.73
	22.71		28.64		17.14	42.86	107.14	0.63	0.75
	20.57		27.57		30.00	42.86	111.43	0.57	0.72
	25.71		34.71		30.00	47.14	120.00	0.71	0.91
	20.00		35.14		21.43	42.86	107.14	0.56	0.92
Extinction									
BL	46.59	6.83	53.20	6.44	30.43	35.14	0.00		
	42.50		48.00		0.00	0.00	0.00	0.91	0.90
	25.50		35.43		0.00	0.00	0.00	0.55	0.67
	18.14		27.64		0.00	0.00	0.00	0.39	0.52
	13.71		18.64		0.00	0.00	0.00	0.29	0.35
	17.14		17.00		0.00	0.00	0.00	0.37	0.32
	5.86		15.50		0.00	0.00	0.00	0.13	0.29
	3.79		5.57		0.00	0.00	0.00	0.08	0.11
	3.86		12.21		0.00	0.00	0.00	0.08	0.23
	0.93		3.07		0.00	0.00	0.00	0.02	0.06

APPENDIX TWO

Appendix 2 presents complete data for all subjects in Experiment 2. Results for each disruption are listed with baseline data (BL) shown first and data from disruption sessions shown subsequently. Columns show responses per minute in Component 1 (P1) and Component 2 (P2), standard deviations for baseline response rates (SD) in the two components, reinforcers per hour in Component 1 (R1), Component 2 (R2) and the intercomponent interval (R3), and the proportions of baseline responding in Component 1 (POB1) and Component 2 (POB2) during sessions of disruption.

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
C1 PHASE ONE									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	27.03	6.42	16.21	4.59	29.57	25.29	0.00		
	34.21		18.71		30.00	34.29	12.86	1.27	1.16
	23.86		13.79		25.71	30.00	30.00	0.88	0.85
	32.21		18.36		30.00	12.86	21.43	1.19	1.13
	19.79		4.14		21.43	25.71	17.14	0.73	0.26
	29.36		9.71		30.00	25.71	25.71	1.09	0.60
	38.50		17.43		34.29	17.14	12.86	1.42	1.08
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	32.70	10.23	18.57	6.60	26.57	28.71	0.00		
	25.93		15.36		30.00	12.86	120.00	0.79	0.83
	27.71		5.29		21.43	25.71	120.00	0.85	0.29
	30.29		22.79		30.00	38.57	107.14	0.93	1.23
	32.71		17.07		38.57	17.14	111.43	1.00	0.92
	19.71		4.00		30.00	17.14	111.43	0.60	0.22
	32.64		12.00		34.29	38.57	120.00	1.00	0.65
	39.36		10.86		21.43	30.00	107.14	1.20	0.59
	28.36		9.71		21.43	30.00	111.43	0.87	0.52
	26.36		15.79		25.71	42.86	115.71	0.81	0.85
	21.29		10.93		30.00	25.71	111.43	0.65	0.59
C1 PHASE TWO (REVERSAL)									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	22.95	4.03	40.09	5.05	36.00	24.86	0.00		
	15.14		39.21		42.86	30.00	17.14	0.66	0.98
	18.14		33.57		34.29	25.71	30.00	0.79	0.84
	5.00		25.14		25.71	30.00	30.00	0.22	0.63
	18.43		47.64		34.29	30.00	25.71	0.80	1.19
	19.07		49.00		30.00	34.29	34.29	0.83	1.22
	28.36		32.86		38.57	21.43	21.43	1.24	0.82
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	23.91	3.38	36.27	3.47	32.14	30.43	0.00		
	13.00		39.21		17.14	42.86	124.29	0.54	1.08
	7.79		26.86		42.86	38.57	111.43	0.33	0.74
	7.36		28.07		17.14	42.86	115.71	0.31	0.77
	7.86		29.00		38.57	38.57	111.43	0.33	0.80
	13.07		23.71		42.86	30.00	120.00	0.55	0.65
	9.50		29.79		34.29	17.14	128.57	0.40	0.82
	15.79		31.57		38.57	42.86	120.00	0.66	0.87
	13.86		25.14		34.29	38.57	115.71	0.58	0.69
	8.71		27.36		21.43	25.71	120.00	0.37	0.75
	7.50		28.07		21.43	30.00	115.71	0.31	0.77

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
C2 PHASE ONE									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	70.81	10.86	54.40	7.34	30.86	31.71	0.00		
	78.86		62.00		30.00	25.71	30.00	1.11	1.14
	68.57		51.93		30.00	42.86	30.00	0.97	0.96
	71.43		55.71		30.00	21.43	30.00	1.01	1.02
	65.36		55.79		25.71	42.86	17.14	0.92	1.03
	69.57		55.29		42.86	34.29	25.71	0.98	1.02
	62.07		57.71		21.43	38.57	38.57	0.88	1.06
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	67.60	4.49	56.70	1.55	36.43	36.00	0.00		
	57.14		51.93		38.57	30.00	120.00	0.85	0.92
	45.00		34.64		25.71	38.57	107.14	0.67	0.61
	43.29		43.36		42.86	34.29	115.71	0.64	0.77
	41.93		39.14		30.00	30.00	124.29	0.62	0.69
	51.29		29.64		38.57	42.86	111.43	0.76	0.52
	52.86		31.29		30.00	30.00	102.86	0.78	0.55
	56.71		32.93		17.14	34.29	111.43	0.84	0.58
	42.71		31.21		42.86	34.29	107.14	0.63	0.55
	48.86		30.93		34.29	38.57	120.00	0.72	0.55
	48.71		33.14		38.57	30.00	115.71	0.72	0.59
C2 PHASE TWO (REVERSAL)									
VT 120-s response-independent reinforcers during the intercomponent interval									
BL	68.09	8.48	72.19	6.90	29.14	31.71	0.00		
	54.07		54.29		25.71	38.57	25.71	0.79	0.75
	56.79		67.07		17.14	42.86	17.14	0.83	0.93
	47.93		52.36		30.00	42.86	38.57	0.70	0.73
	41.57		55.93		30.00	42.86	25.71	0.61	0.78
	68.50		68.64		34.29	25.71	21.43	1.01	0.95
	58.71		51.50		30.00	42.86	21.43	0.86	0.71
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	63.66	5.94	65.31	4.15	31.29	33.43	0.00		
	24.07		25.50		34.29	30.00	120.00	0.38	0.39
	25.71		28.57		38.57	42.86	102.86	0.40	0.44
	30.07		36.57		21.43	21.43	111.43	0.47	0.56
	31.71		32.36		30.00	38.57	111.43	0.50	0.50
	25.57		37.79		17.14	25.71	124.29	0.40	0.58
	21.64		24.86		21.43	25.71	128.57	0.34	0.38
	27.93		26.00		34.29	25.71	111.43	0.44	0.40
	23.71		28.50		34.29	17.14	115.71	0.37	0.44
	24.64		18.64		47.14	17.14	120.00	0.39	0.29
	26.21		25.93		30.00	34.29	115.71	0.41	0.40

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
C3 PHASE ONE									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	44.37	8.78	32.71	8.96	28.29	33.43	0.00		
	38.50		26.71		47.14	21.43	38.57	0.87	0.82
	42.14		31.64		34.29	30.00	25.71	0.95	0.97
	47.36		30.29		25.71	38.57	17.14	1.07	0.93
	30.64		27.64		25.71	34.29	34.29	0.69	0.85
	41.00		29.07		34.29	34.29	30.00	0.92	0.89
	44.29		31.21		42.86	38.57	8.57	1.00	0.95
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	52.99	9.32	39.34	6.32	28.29	34.29	0.00		
	31.29		21.07		42.86	42.86	111.43	0.59	0.54
	30.07		15.71		34.29	42.86	115.71	0.57	0.40
	30.50		23.00		30.00	47.14	107.14	0.58	0.59
	32.14		20.50		34.29	42.86	132.86	0.61	0.52
	26.00		11.57		47.14	30.00	124.29	0.49	0.29
	32.00		17.07		34.29	30.00	124.29	0.60	0.43
	35.64		24.79		42.86	42.86	111.43	0.67	0.63
	31.71		14.57		25.71	25.71	111.43	0.60	0.37
	25.36		19.07		25.71	30.00	102.86	0.48	0.49
	28.71		14.57		38.57	42.86	124.29	0.54	0.37
C3 PHASE TWO (REPLICATION)									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	66.05	9.87	35.92	4.97	38.14	31.71	0.00		
	50.50		27.79		21.43	42.86	30.00	0.77	0.77
	61.14		30.64		42.86	21.43	38.57	0.93	0.85
	45.14		18.71		17.14	38.57	25.71	0.68	0.52
	45.64		20.00		42.86	38.57	34.29	0.69	0.56
	48.00		24.29		34.29	34.29	34.29	0.73	0.68
	50.79		21.50		30.00	51.43	38.57	0.77	0.60
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	64.91	7.15	43.76	4.27	36.86	35.14	0.00		
	48.36		21.14		42.86	42.86	120.00	0.75	0.48
	30.07		12.79		30.00	38.57	120.00	0.46	0.29
	31.36		18.07		38.57	38.57	120.00	0.48	0.41
	38.21		19.93		21.43	47.14	111.43	0.59	0.46
	32.50		14.64		21.43	21.43	102.86	0.50	0.34
	31.07		12.07		47.14	21.43	107.14	0.48	0.28
	24.29		10.07		25.71	30.00	115.71	0.37	0.23
	35.21		12.21		38.57	34.29	124.29	0.54	0.28
	31.00		11.07		30.00	34.29	115.71	0.48	0.25
	34.14		12.71		38.57	38.57	128.57	0.53	0.29

	P1	(SD)	P2	(SD)	R1	R2	R3	POB1	POB2
C4 PHASE ONE									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	34.84	4.05	21.99	4.77	29.14	29.57	0.00		
	44.07		20.71		34.29	42.86	17.14	1.27	0.94
	32.43		12.57		34.29	42.86	17.14	0.93	0.57
	33.93		9.43		21.43	30.00	30.00	0.97	0.43
	28.21		9.86		38.57	17.14	30.00	0.81	0.45
	37.57		10.00		42.86	25.71	17.14	1.08	0.46
	30.43		6.64		42.86	34.29	17.14	0.87	0.30
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	42.62	8.62	19.89	4.43	34.29	26.57	0.00		
	17.86		6.64		25.71	25.71	120.00	0.42	0.33
	14.57		4.79		30.00	25.71	115.71	0.34	0.24
	19.14		6.43		34.29	38.57	111.43	0.45	0.32
	21.00		5.93		25.71	25.71	111.43	0.49	0.30
	20.43		2.50		30.00	8.57	111.43	0.48	0.13
	19.79		5.57		17.14	34.29	111.43	0.46	0.28
	29.64		8.93		30.00	38.57	115.71	0.70	0.45
	17.07		11.07		21.43	42.86	111.43	0.40	0.56
	26.21		14.00		42.86	34.29	115.71	0.62	0.70
	18.57		7.93		25.71	30.00	115.71	0.44	0.40
C4 PHASE TWO (REPLICATION)									
VT120-s response-independent reinforcers during the intercomponent interval									
BL	44.15	5.44	24.80	5.46	33.86	33.86	0.00		
	28.07		13.50		34.29	21.43	21.43	0.64	0.54
	30.71		19.57		47.14	34.29	21.43	0.70	0.79
	34.14		13.79		21.43	17.14	17.14	0.77	0.56
	22.50		6.14		42.86	25.71	30.00	0.51	0.25
	37.57		17.29		38.57	25.71	25.71	0.85	0.70
	23.29		10.93		34.29	42.86	25.71	0.53	0.44
VT 30-s response-independent reinforcers during the intercomponent interval									
BL	38.19	3.73	22.86	4.15	33.00	33.86	0.00		
	20.29		8.64		42.86	30.00	111.43	0.53	0.38
	15.29		8.57		25.71	38.57	107.14	0.40	0.38
	19.79		10.07		17.14	21.43	115.71	0.52	0.44
	16.93		8.07		25.71	30.00	124.29	0.44	0.35
	23.21		12.64		25.71	12.86	107.14	0.61	0.55
	23.43		10.14		42.86	34.29	120.00	0.61	0.44
	24.71		9.43		25.71	21.43	115.71	0.65	0.41
	20.79		10.57		42.86	38.57	102.86	0.54	0.46
	24.86		8.50		34.29	25.71	111.43	0.65	0.37
	20.21		8.29		17.14	38.57	115.71	0.53	0.36